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ABSTRACT

The student's manual in this two-part instructional kit is designed to help the following types of students learn introductory technical material related to pneumatics: (1) groups of trade and industrial students with a variety of vocational objectives and (2) homogeneous groups in which the learning levels of individual students vary considerably. The manual is not intended to be used as a type of correspondence course, but must be used by students under the direct supervision of an instructor. The manual contains nine assignments covering the following topics: how to use the manual, introduction, air compressors, plastic piping, copper piping, conditioning compressed air systems, pressure gauges and volume meters, pneumatic working elements, and pneumatic valves. The student's manual is designed to use as many fundamental teaching principles as possible. Each assignment has four parts: objectives, technical information presented in a step-by-step fashion, exercises to apply the technical information, and tests (provided in the instructor's guide). The instructor's guide is designed to help teachers make certain that each student gets the greatest possible benefit out of both the student's manual and the training station sessions. Coordinated with the student manual, it provides the answers to the exercises in the manual and contains, beside the assignment test questions, the answers to the questions, and a worksheet to help in coordinating work experiences with the assignments. (KC)

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PNEUMATICS

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Pneumatics

Student's Manual

Prepared By

Troy Notgrass

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COMPLIANCE STATEMENT

TITLE VI, CIVIL RIGHTS ACT OF 1964; THE MODIFIED COURT ORDER, CIVIL ACTION NO. 5281, FEDERAL DISTRICT COURT, EASTERN DISTRICT OF TEXAS, TYLER DIVISION

Reviews of local education agencies pertaining to compliance with Title VI Civil Rights Act of 1964 and with specific requirements of the Modified Court Order, Civil Action No. 5281, Federal District Court, Eastern District of Texas, Tyler Division are conducted periodically by staff representatives of the Texas Education Agency. These reviews cover at least the following policies and practices:

- (1) acceptance policies on student transfers from other school districts;
- (2) operation of school bus routes or runs on a non-segregated basis;
- (3) nondiscrimination in extracurricular activities and the use of school facilities;
- (4) nondiscriminatory practices in the hiring, assigning, promoting, paying, demoting, reassigning, or dismissing of faculty and staff members who work with children;
- (5) enrollment and assignment of students without discrimination on the basis of race, color, or national origin;
- (6) nondiscriminatory practices relating to the use of a student's first language; and
- (7) evidence of published procedures for hearing complaints and grievances.

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TITLE VII, CIVIL RIGHTS ACT OF 1964; EXECUTIVE ORDERS 11246 and 11375; TITLE IX 1973 EDUCATION AMENDMENTS; REHABILITATION ACT OF 1973 AS AMENDED; 1974 AMENDMENTS TO THE WAGE-HOUR LAW EXPANDING THE AGE DISCRIMINATION IN EMPLOYMENT ACT OF 1967; VIETNAM ERA VETERANS READJUSTMENT ASSISTANCE ACT OF 1972 AS AMENDED IN 1974.

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Foreword

This publication is one of a series of self-contained instructional materials for trade and industrial students. Each student who uses this material can work at his or her own pace, learning those things that best fit her or his specific needs. The design of the material makes it possible to relate work experience on the job to information studied at school.

Although the material is individualized, it should be used under the supervision of an instructor. For that reason, two basic publications are offered, a student's manual and an instructor's guide.

The **student's manual** is for the use of the person in training. Each assignment includes appropriate information, objectives to be met, and exercises that help in meeting those objectives.

The **instructor's guide** provides information to the instructor on how to use the material to the best advantage of the student, answers to exercise questions and assignment test questions, one set of assignment tests, and a work sheet.

Every effort has been made to produce a publication that addresses the unique needs of our current student population. Students with limited English proficiency (LEP), as well as handicapped, educationally disadvantaged, and nontraditional students may require modification of the material in this publication. The professional staff of EIMC will gladly work with any instructor having these students to show how the instructional material can be adapted for specific individualized instruction. Consult local, state, and federal agencies that offer assistance and guidance and that can provide sound recommendations for productive classroom management.

Kathryn R. Allen, Ph.D.
Director, Extension Instruction
and Materials Center

A Special Note to the Student

The assignments in this manual are designed to help you learn. You will gain more from this material if you know how to work the assignments. For that reason, Assignment 1, which is about how to use this manual, should be completed first.

1

How to Use This Manual

Objectives: After completing this assignment, you will be able to—

1. state the author's first concern in writing this manual;
 2. list the four parts of each assignment;
 3. state the purpose of the objectives;
 4. tell the proper sequence of study for each assignment; and
 5. explain why the assignment test should be a snap.
-

You, the student, might be surprised if you knew how closely your interest in this manual and that of the author compare. For instance, did you know that the author's first concern was to make learning as easy as possible? In fact, the organization of this manual has been based on how to make the information in each assignment easy to learn and easy to retain in your mind. Each assignment has four parts: (1) the learning **objectives** of the assignment, (2) the **technical information**, (3) the **exercise**, and (4) the **assignment test**. When studied in this order, this arrangement should provide you with the greatest learning opportunity.

To illustrate, go back—right now—and reread the objectives. Had you really paid any attention to the objectives the first time you read them? They are important because they tell you what you should be able to remember after completing this assignment. You read the objectives so you will know the important information to look for. Then, as you read, things you need to know will literally pop into your mind. A short assignment test has been written for each assignment. The questions test the very information the objectives said was important to learn.

Be sure to read the objectives first, the technical information second, and then answer the questions in the exercise. This

order has a purpose. First, you learn from the objectives what to look for when reading. Then you read and learn the information needed to meet the objectives. The exercise questions then guide you for a third time over the facts considered important. This drill ingrains the information in your mind.

If you are in a co-op class, your notebook should show anyone what you have studied during the time you have been in the program. The following rules may be useful in answering the exercise questions. Of course, if your instructor has certain rules, by all means follow them.

1. All work should be done on regular two-, three-, or five-hole theme paper—never on spiral notebook paper.
2. Either (a) write the answers in complete sentences or (b) write the questions and then write only the answer on the line below.
3. For your own benefit, include a correction sheet in your notebook. You can write down the correct answers after the exercises have been checked by your instructor.

A word of caution in working the exercises: **do not hurry through the questions.** Take your time and learn each assignment as you go. Your instructor is not interested

in **how many assignments you turn in**. His or her main concern is **how much you have learned**. Just stay busy, do your work, and let the number of assignments turned in take care of itself.

A further word of caution: study each assignment within a section in its numerical order. Each assignment is basic to understanding the next assignment within each section.

If you study each assignment as instructed here, the fourth part—the test—will be a snap. That is because you will have covered the information three times before taking the test. The test is based on information stated in the objectives.

If you do not do well on the test, go back to the objectives, and study the assignment again. After reading the objectives and the technical information and completing the exercise, ask your instructor to retest your knowledge. If you still do not do well, perhaps the author should redo the assignment! This goes back to the statement that your interest in this manual is the same as that of the author. You see, if you

fail to learn, the author, through this manual, has failed to teach.

Exercise

1. How does your interest in this manual and that of the author compare?
2. List the four parts of each assignment.
3. Why are the objectives important?
4. Of what secondary importance are the objectives?
5. Give the proper sequence or order of study so that you can learn the most from each assignment.
6. What is the purpose of studying the assignment in the proper order?
7. Why is the kind of paper you use and the way you answer questions of importance?
8. If your instructor is not particularly interested in how many assignments you turn in, what is he or she concerned about?
9. Why should the short test be a snap?
10. Explain how the success or failure of the author depends on how well you do.

2

Introduction

Objectives: After completing this assignment, you will be able to—

1. explain the advantages of using pneumatics;
 2. explain the disadvantages of using pneumatics;
 3. explain how to determine the amount of pressure in a container; and
 4. explain how to determine the amount of force in a container.
-

The word **pneumatics** is based on the Greek word for air. However, its meaning generally refers to a pressurized air system designed to do work. Pneumatic systems are used to transmit force from one point to another and to multiply force. There are several **advantages** to using pneumatics instead of some mechanical means.

1. Air is available at any place in unlimited quantities merely for the taking.
2. Air can be easily transported through pipelines to any point desired.
3. Air is stable, even under temperature changes. Since air does not burn or explode, no protection from explosions is required.
4. Compressed air is clean. It does not contain contaminants or corrosive elements that cause leaks in the pneumatic system.
5. Pneumatic speeds and forces are infinitely variable.
6. Pneumatic tools and equipment are overload safe. That is, they can be loaded until they stop without producing an explosion or breaking the tools or equipment.

Along with the advantages of pneumatics, it should be also understood that certain **disadvantages** must be overcome.

1. Compressed air requires proper preparation. Dirt and humidity must be removed from the system because each will cause undue wear on the components.
2. It is not possible to achieve uniform and constant equipment speeds with compressed air.
3. In most instances, compressed air is not an inexpensive means of conveying power.

Three basic principles are important to pneumatics:

1. **Gases are shapeless.** While solids always have a definite shape, gases conform to the shape of their containers. Since they do conform to any shape, they are easily piped almost anywhere.

2. **Gases are highly compressible.** This means that it is impossible to maintain a constant, or even, pressure during use.

3. **Gases transmit applied pressure equally in all directions** (fig. 1). Every square inch of the inside of a container, regardless of its shape, has an equal pressure exerted on it. This pressure is always

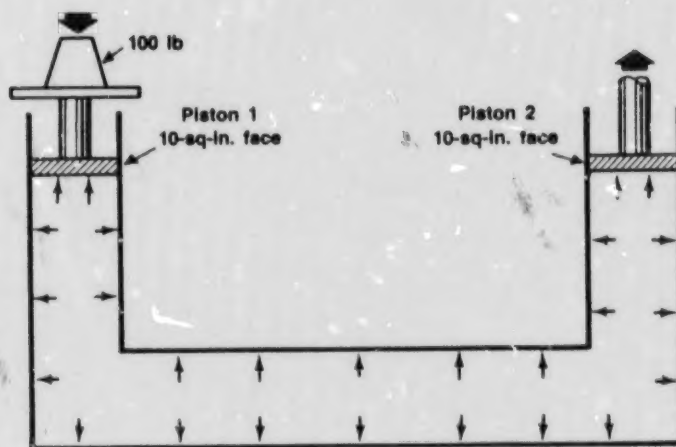


Fig. 1. Gas transmits applied pressure equally in all directions.

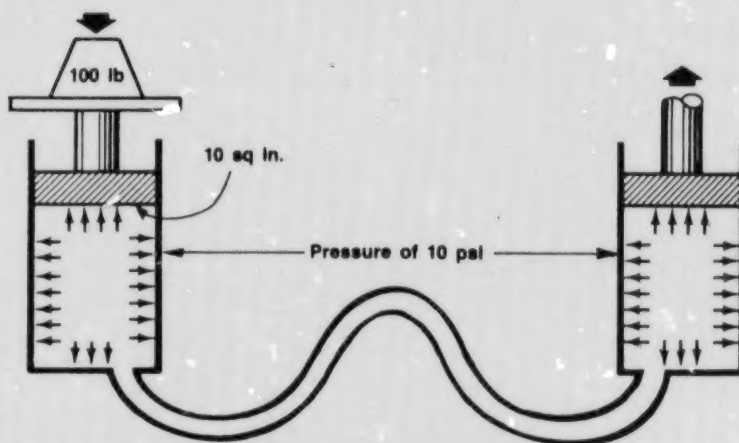


Fig. 2. Pressure equals force divided by area.

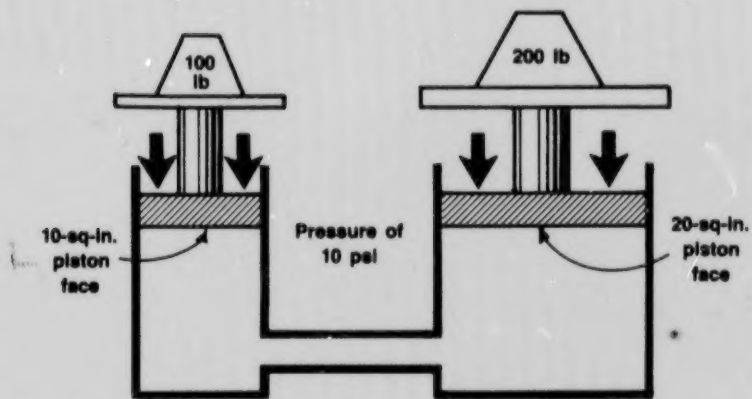


Fig. 3. Force can be multiplied by increasing the size of the receiving piston.

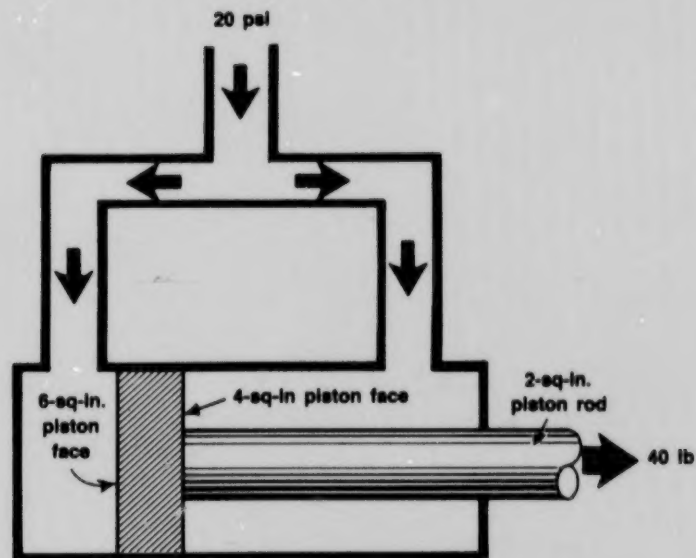


Fig. 4. Different areas on the two faces of one piston create directional force.

exerted at right angles to the inside wall. The shape of the container does not alter the pressure exerted by the gas.

Pressure is defined as **force divided by the area** over which the pressure is distributed. In figure 2, a 100-pound weight is placed on piston 1. This piston's face is 10 square inches. Therefore, it exerts 10 pounds per square inch on the gas. This pressure is distributed equally throughout the entire system. Piston 2 also has 10 square inches on its face. This means that 100 pounds of force is exerted on the piston (force = pressure x area).

This points out an interesting fact about pressure and force. Although they are directly related, they are not one and the same. While the pressure in a system may remain constant, the force exerted by the pressure is proportional to the square inches of surface area upon which the pressure is exerted. This means that force may be multiplied. For instance, in figure 3, a 100-pound weight is applied to piston 1, which has 10 square inches on its face. This exerts a pressure of 10 pounds per square inch (psi) on the system. Piston 2 has 20 square inches on its face. This means that 10 psi is exerted on twice as many square inches on piston 2 as on piston 1. Therefore, 200 pounds of force is exerted on piston 2.

Multiplication of force is possible because of the difference in the areas of the pistons, usually called **differential areas**. Differential areas do not have to be on two different pistons. They can be, and sometimes are, on the same piston. Figure 4 shows a single piston in a cylinder having a piston rod attached to one side of the piston. Pneumatic pressure is admitted to both ends of the cylinder equally through the

pipes. The opposed faces of the piston behave as two pistons acting against each other. The area of one face is the full area of the cylinder (6 square inches), while the area of the other face is equal to the area of the cylinder minus the area of the piston rod (2 square inches). This leaves the effective area of 4 square inches on the right face of the piston. Obviously, the pressure on both sides of the piston will be the same, 20 psi. Using the formula to determine force, we multiply 20 times 6, which equals 120 pounds. Using the same formula, the force on the right side is 80 pounds. There is a net unbalanced force of 40 pounds acting to the right. The piston will move in that direction.

Exercise

1. What is the word **pneumatics** based on?
2. What are six advantages to using pneumatics rather than some mechanical means?
3. What are three disadvantages of using pneumatics?
4. How does the shapelessness of gases affect their transportability?
5. How does the highly compressible nature of gases affect their use as a source of power?
6. How is the gas pressure distributed in a container?
7. How is **pressure** defined in the text?
8. What is the formula for finding the amount of force exerted on or by a piston?
9. How is force increased?
10. What are differential areas?
11. What is the purpose of using differential areas?

3

Air Compressors

Objectives: After completing this assignment, you will be able to—

1. explain how the different compressors discussed operate;
 2. explain the function of the parts of each compressor; and
 3. explain the advantages of each of the different types of compressors.
-

There are two basic types of compressors used in industry. One is the positive displacement type, and the other is the airflow or velocity type. The type selected depends on operational demands, working pressure, and delivery volume.

Positive Displacement Compressors

Positive displacement means that a measurable volume of air is displaced in a complete cycle of a reciprocating piston or revolving rotor equipped with lobes or vanes. Positive displacement compressors are divided into the reciprocating piston type or the rotary type.

Figure 1 illustrates a simple **reciprocating piston compressor**. As the crankshaft rotates, it pulls the piston downward. The intake valve opens and allows air to be drawn into the cylinder from the atmosphere. Actually, pressure from the atmosphere pushes air into the cylinder as the piston moves downward, creating a vacuum. Notice that the exhaust valve is closed during the downward stroke. Figure 2 illustrates the upward stroke of the compressor. As the crankshaft continues its rotation, the piston reaches the bottom of its stroke and begins to move upward. As it begins to move upward, the intake valve closes and the exhaust valve opens. The piston forces the air from the cylinder as it moves

upward. The air moves through the exhaust manifold and piping to the storage tank. This type of compressor is used for low and medium pressure requirements.

Figure 3 shows the intake stroke of the first stage and the exhaust stroke of the second stage of a **two-stage**, high-pressure air compressor. First, notice that the second stage of the compressor has a smaller cylinder and piston than the first stage. This is because the air has been compressed by the first stage. The air charge no longer occupies the same volume that it did previously. If the second-stage cylinder and piston were as large as the first stage, the second stage could offer no further compression of the air. The air would simply expand to its original volume and then be compressed to the same pressure that was provided by the first stage.

The first stage operates the same as the simple single-stage compressor, shown in figures 1 and 2. However, the air is exhausted into the manifold to the second-stage cylinder intake rather than to a storage tank. The second stage compresses the air still further. The "V" arrangement of the compressor causes the two pistons to have an overlap of the compression and exhaust strokes. The timing of the opening of the exhaust valve of the first stage and the intake valve of the second stage is engineered so that the air is delivered from

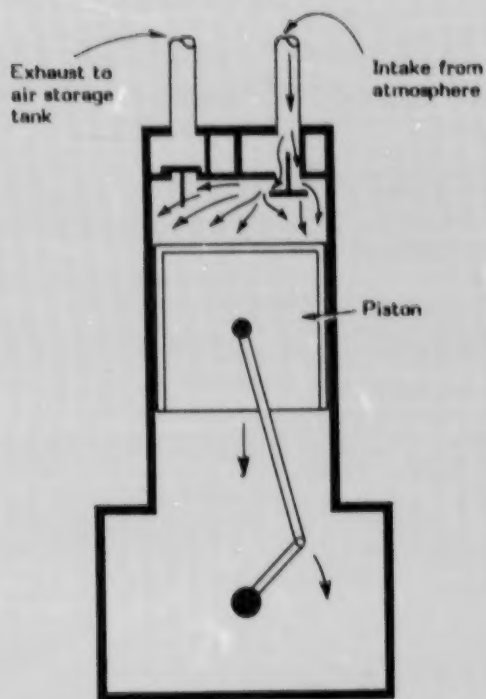


Fig. 1. Intake stroke of a single-stage air compressor

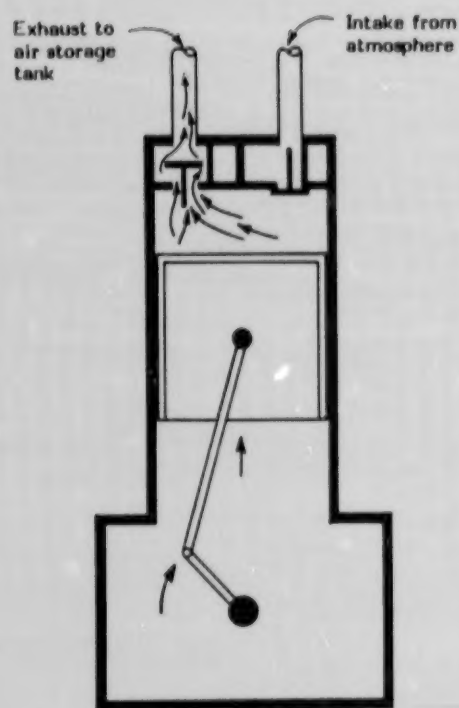


Fig. 2. Exhaust stroke of a single-stage air compressor

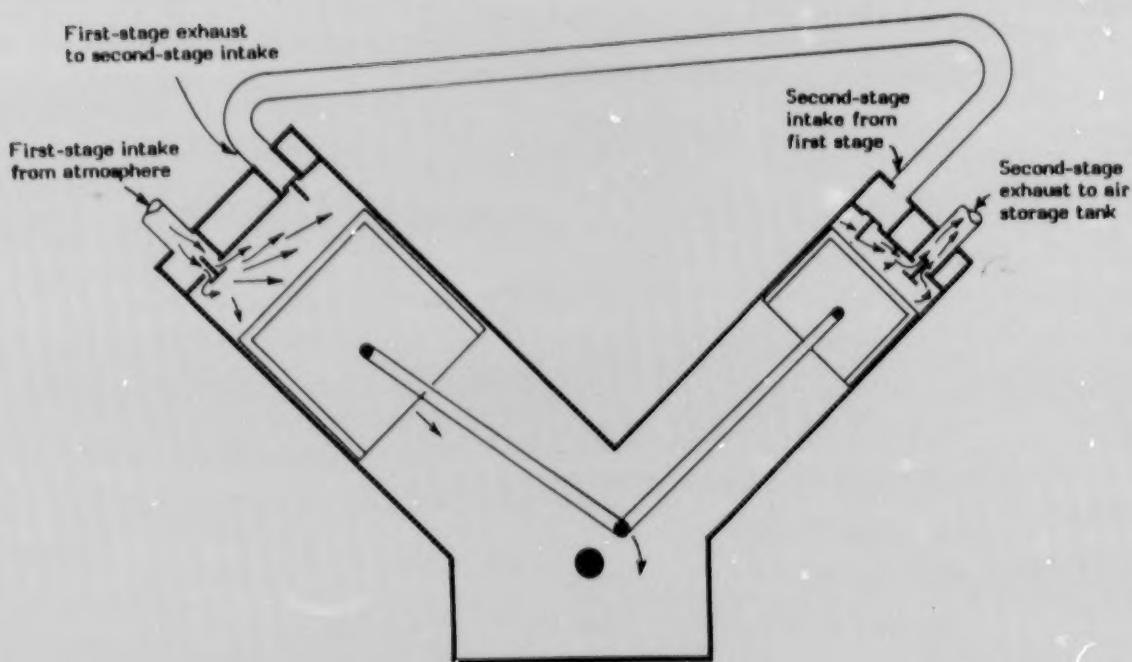


Fig. 3. First-stage intake and second-stage exhaust strokes of a two-stage air compressor

the first stage to the second stage only when the first-stage cylinder is under compression and the second-stage cylinder is under a vacuum.

Another type of positive displacement compressor is the **diaphragm compressor**. As shown in figure 5, the compressor piston is separated from the air chamber by a diaphragm. The purpose of the diaphragm is to prevent contamination of the air by the lubricating oil for the crankshaft and piston. As the piston rises, it lifts the diaphragm, which is a flexible material that does not bend or buckle as it is compressed. On the exhaust stroke, the intake valve is closed and the exhaust valve is open. As the volume in the air chamber is reduced by the compressing diaphragm, the air is forced out and into the exhaust manifold and piping and to the storage tank. When the piston begins to move downward, the diaphragm will move downward also, increasing the volume in the air chamber. Atmospheric pressure causes the air to flow into the air chamber, making it ready for the exhaust stroke again.

A **lobe-type compressor** is shown in figure 6. Although figure 6 shows a compressor with two rotors with three lobes each, many are designed with two rotors with two lobes each. The working parts of the compressor consist of two accurately machined rotors that rotate in opposite directions. The lobes of the rotors (impellers) mesh closely together as they rotate. As the impellers rotate, air is trapped in the opening between the lobes and the housing. The air is forced into the outlet opening when the lobes mesh. The three-lobe type of compressor may have lobes made parallel to the shaft or made in a spiral. The lobes are made in a spiral to reduce the impulse of air and give a smooth airflow to the piping. The advantage of the three-lobed impeller is that it is not as noisy as the two-lobed impeller and it delivers a smoother flow of air. The two-lobed impeller delivers the greatest amount of air from a given sized housing and uses less power than the three-lobed impeller.

Figure 7 illustrates a **sliding vane type compressor**. The sliding vanes form and seal air chambers formed around an offset rotor in a circular housing. The vanes fit in slots in the rotor. Centrifugal force holds the vanes in contact with the housing. On the intake side of the chamber, air is drawn in

as the rotor turns and the vanes extend further out from the center of the rotor. This increases the volume of the space between the vanes. The vanes begin to move back toward the center of the rotor after it has reached the midpoint of the chamber. As the chamber is reduced in size, air is forced out the exhaust and into the piping to the storage tank. The advantages of a sliding vane compressor are that it is compact, quiet running, and delivers a smooth, steady flow of air.

Airflow or Velocity Compressors

An **axial flow or turbine compressor** (fig. 8) has an impeller that is provided with vanes and rotates at high speeds in a carefully designed housing. The impeller normally rotates at 15,000 to 30,000 revolutions per minute (rpm). Air enters the housing near the center of the impeller and is thrown outward by centrifugal force. The shape of the housing funnels the air and transforms its high velocity into pressure.

A **radial flow or centrifugal air compressor** (fig. 9) is composed of several chambers called stages. An impeller is located in each stage. Each stage of the compressor increases the pressure of the air and routes it to the next stage. Thus, air enters the first stage, and the rotating impeller throws the air outward. The air follows the chamber to the outer walls and then is routed back to the center and into the second stage. The same procedure is followed in each of the stages. The air pressure is increased at each stage. In the final stage, the air is routed through the piping to the storage tank or to the working components of the system.

Exercise

1. What is meant by the term **positive displacement**?
2. What causes the air to enter the cylinder as the piston moves downward?
3. For what is the simple reciprocating piston compressor used?
4. What is the purpose of the second stage of the two-stage compressor?
5. Why are the second-stage cylinder and piston smaller than the first stage?
6. What would happen if the second stage were the same size as the first stage?

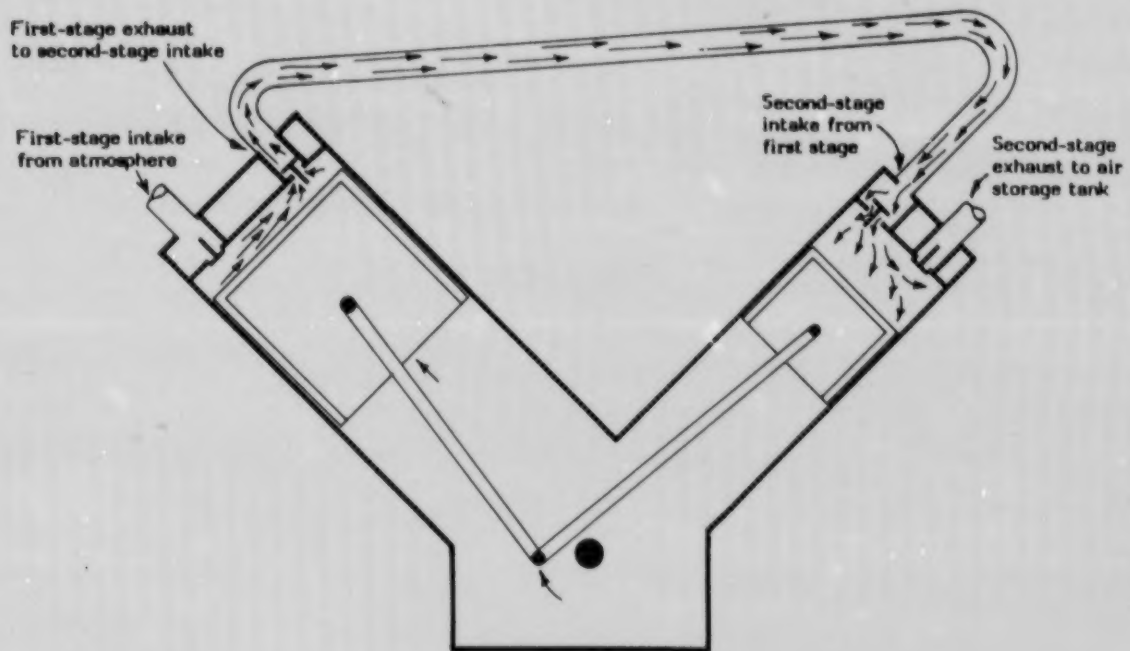


Fig. 4. First-stage exhaust and second-stage intake strokes of a two-stage air compressor

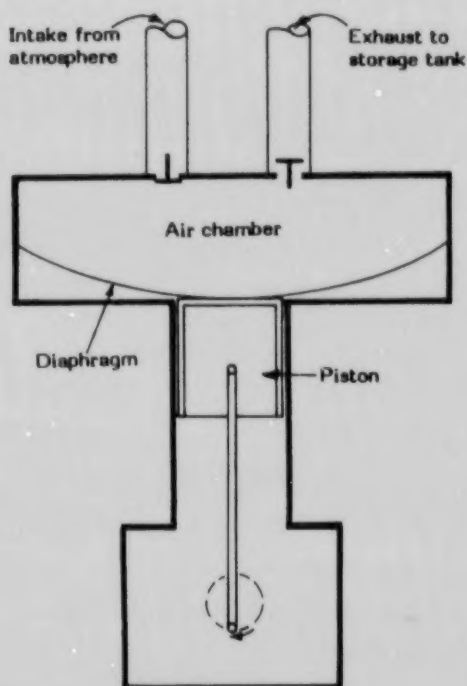


Fig. 5. Beginning of the exhaust stroke of a diaphragm compressor

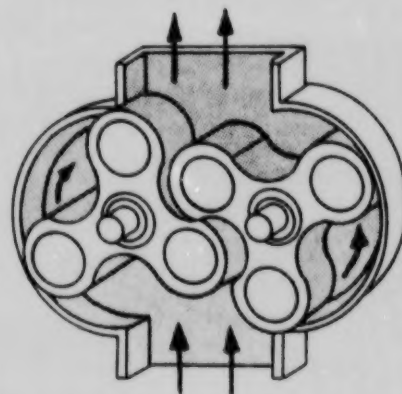


Fig. 6. Cutaway view of a three-lobed air compressor

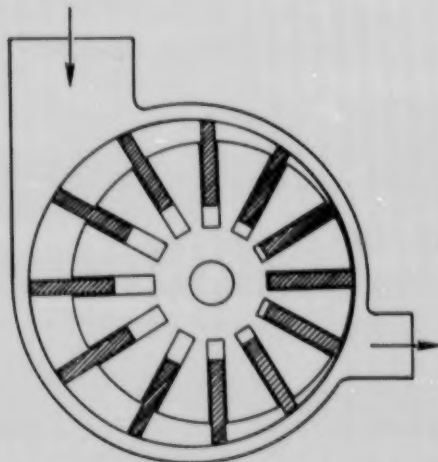


Fig. 7. Cutaway view of a sliding vane air compressor

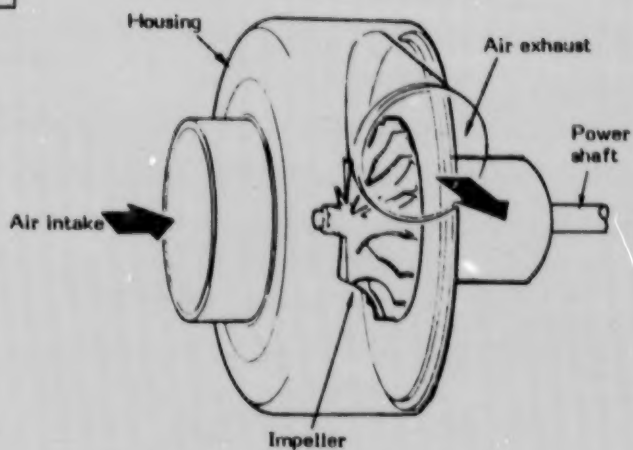


Fig. 8. An axial flow or turbine air compressor

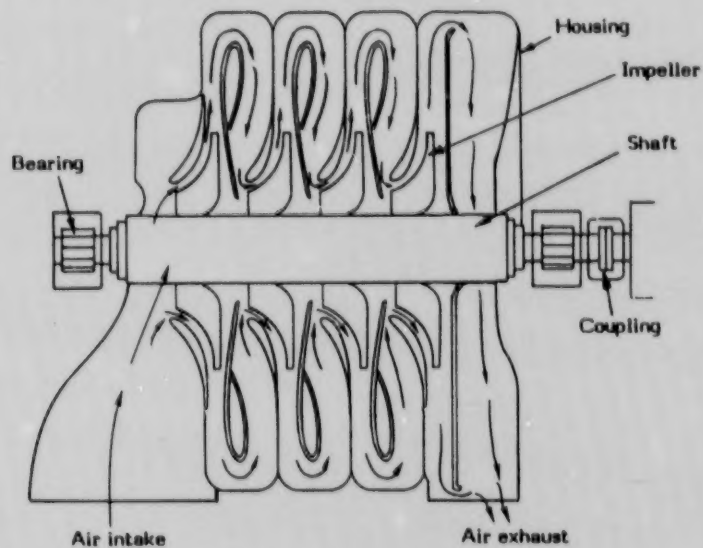


Fig. 9. Cutaway view of a radial flow or centrifugal air compressor (Courtesy Compressed Air and Gas Institute)

7. How does the "V" arrangement of the two-stage compressor affect the relationship between the compression and exhaust strokes of the two cylinders?
8. What is the purpose of the diaphragm in a diaphragm compressor?
9. How many lobes may be on the rotors of a lobe-type compressor?
10. How is air pumped or compressed by the rotors?
11. Why will the lobes on the impeller be made in a spiral?
12. What are the advantages of the three-lobed impeller?
13. What are the advantages of the two-lobed impeller?
14. How are the air chambers formed in a sliding vane compressor?
15. What causes the air to be drawn into the sliding vane compressor?
16. What causes the air to be forced from the chambers of a sliding vane compressor?
17. What are the advantages of a sliding vane compressor?
18. At what speeds do axial flow or turbine compressors operate?
19. Where does air enter the turbine compressor?
20. What transforms the high velocity of the air in a turbine compressor into pressure?
21. What is the purpose of the various stages in the radial flow or centrifugal air compressor?

4

Plastic Piping

Objectives: After completing this assignment, you will be able to—

1. explain the factors that govern designing a pneumatic system;
 2. list the characteristics of PVC and CPVC pipe;
 3. explain how to prepare plastic pipe ends and sockets for joining;
 4. explain how to apply the solvent cement; and
 5. explain how to join the pipe and socket.
-

When designing a piping system for a pneumatic application, several factors should be considered. Of primary importance is providing a system that prevents contamination and that does not leak. The following factors should be used as guidelines in judging which pipe to use in a pneumatic system.

(1) **Flow volume.** Both current needs and future needs should be considered when planning a piping system. The pipe should be large enough to carry the volume of air required at peak periods of use. Since most businesses grow with time, the system should be designed to handle the added load. One method of increasing the volume of air available is to design the system in the shape of a loop (fig. 1). This permits air to flow in two directions to the point of greatest use.

(2) **Pressure drop.** The resistance in the piping system to airflow causes the pressure to drop between the point at which the air enters the system and the point at which it is used. This pressure drop is increased by turns, length, and number of connections. A general rule is that the pressure drop should not exceed 10 percent. Thus, long lines should be equipped with larger pipe than shorter lines have. The piping system should be routed as close as possible to the points

of use to reduce the hose lengths required at the points of use.

(3) **Pipe location.** In addition to determining the correct pipe size, it is important to locate the pipe so that it can be serviced. This means that the pipe should not be located inside walls, particularly in brickwork or narrow pipe shafts. The pipe should also be installed so that it has a 1 to 2 percent drop in the direction of flow. This prevents condensation from filling the pipe. In horizontal runs of pipe, branches should be made from the top of the pipe. This prevents the condensation from entering the branch line.

(4) **Pipe material.** Several types of pipe are available for pneumatic systems: copper, brass, steel tubing, and plastic. Since the main lines must be resistant to corrosion and inexpensive to install, plastic pipe is increasing in popularity. However, copper and steel pipe systems continue to be installed.

Plastic Pipe

PVC (polyvinyl chloride). PVC is a rigid pipe that is normally available in 20-foot sections. It has the following characteristics:

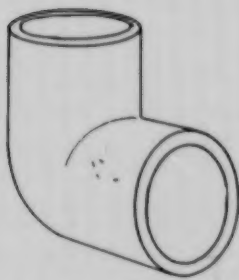


Fig. 1. 90° ell, pipe to pipe (Courtesy NIBCO Inc.)

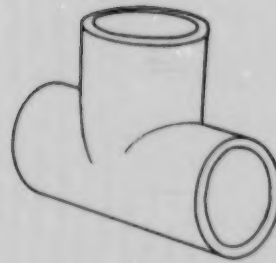


Fig. 2. Tee, pipe to pipe to pipe (Courtesy NIBCO Inc.)

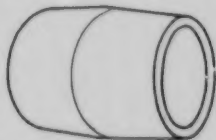


Fig. 3. Coupling, pipe to pipe

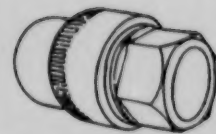


Fig. 4. Union, pipe to copper

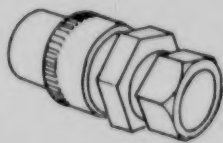


Fig. 5. Union, pipe to compression (Courtesy NIBCO Inc.)

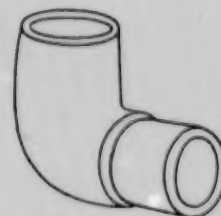


Fig. 6. 90° fitting ell to pipe (Courtesy NIBCO Inc.)

(1) It is inert to attack by strong acids, alkalies, salt solutions, alcohols, and many other chemicals. It is noncorrosive.

(2) It provides both high tensile strength and high impact strength and can withstand high pressures for long periods, even at elevated temperatures.

(3) It has excellent outdoor weathering ability. Even in direct sunlight, it needs no protection. It is resistant to fungi, bacterial action, and adverse soil conditions.

(4) The high dielectric properties of PVC prevent electrolytic corrosion, regardless of the kind of soil in which the pipe is used.

(5) PVC pipe is lightweight. Ten feet of 2-inch pipe weigh only 6 pounds. This permits lighter and less expensive supporting structures. Also, installation is easier in hard-to-get-to places.

(6) The mirror-smooth "nonwetable" interior surface of PVC pipe provides less flow resistance.

(7) Joints are made quickly and easily by solvent welding the fitting to the pipe. The joints become stronger than the pipe itself. The weld does not oxidize or corrode even in locations where moisture is always present in the system.

(8) The pipe itself cannot support combustion.

CPVC (chlorinated polyvinyl chloride). CPVC has all the physical characteristics of PVC, with two added features. It remains serviceable up to 230°F, and the pipe itself is self-extinguishing.

PVC and CPVC Schedule 40 pressure fittings are shown in figures 2 through 8.

Solvent Welding

Primer and solvent. Solvent cement is applied to the surfaces of the pipe and the fitting to be joined. The surfaces of each of the two are etched or chemically attached. The surfaces are temporarily softened or melted. While they are in this condition, the pipe is inserted into the fitting. The two surfaces begin to quickly harden again. However, as they harden, the two surfaces are **welded into a single piece**. The joint is stronger than the pipe or the fitting. Both PVC and CPVC require a primer as well as a solvent. Many people, even experienced people, do not use a primer before applying the solvent when joining PVC and CPVC

pipe. However, studies into pipe failures have revealed that almost all failures resulted from installing pipe that did not meet specifications or from using incorrect procedures in making joints.

Be sure the primer is the correct one for the pipe being joined. There is no such thing as a totally satisfactory "universal" solvent cement.

Solvent welding compounds are flammable and evaporate quickly. They should not be opened until you are ready to use them, and they should be kept in a shady place when not in use. The solvent cement should be discarded (1) when it begins to thicken or (2) at the first sign of gelation. A gelatin condition is indicated when the solvent does not flow freely from the brush or when the solvent appears lumpy and stringy. Do not add thinners or solvents.

Preparing the pipe. Cut the pipe squarely (fig. 9). Use a fine-toothed hand saw and a miter box. A rotary cutter may be used if the cutting blade is specifically designed for cutting plastic pipe. If the end is not cut squarely, the pipe will not seat correctly in the fitting. A weak joint will result.

Remove all ridges made at the pipe end (fig. 10). Failure to remove the ridges will result in the solvent being scraped from the socket surface. The resulting dry joint will have a high probability of failure. Remove all burrs with a knife, file, or abrasive paper. **A chamfered end makes a better joint** (fig. 11).

Join the two pieces that are to be mated. The pipe should fit about halfway into the socket. This is called an **interference fit**. Actually, the socket is slightly bell-mouthed. That is, the diameter of the socket is slightly greater at the outer edge than it is at the seat (fig. 12).

Applying solvent. Be sure the surfaces of PVC or CPVC pipe are cleaned before applying primer. Use only primer specifically made for PVC and CPVC. Use the brush provided in the cap of the primer. First, apply an even coat to the inside of the fitting. Be careful **not to leave a puddle** in the bottom of the fitting. Then, apply an even coat to the outside of the pipe to the depth that will be taken into the fitting when it is seated. Wait for 15 seconds before applying the solvent.

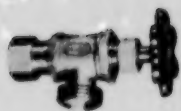


Fig. 7. Drain valve, compression to hose (Courtesy NIBCO Inc.)

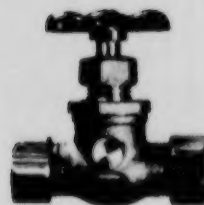


Fig. 8. Stop and waste valve, compression to compression (Courtesy NIBCO Inc.)

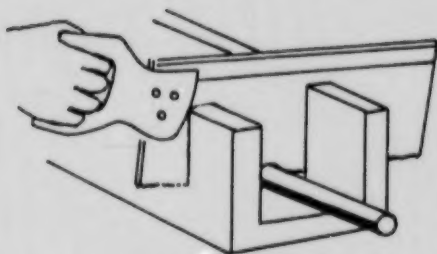


Fig. 9. Cut pipe squarely.



Fig. 10. Remove all burrs and ridges.

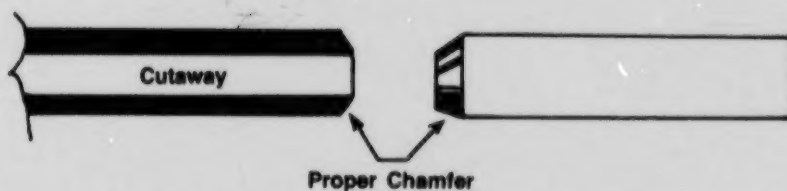


Fig. 11. Better joints are made with chamfered ends. (Courtesy NIBCO Inc.)

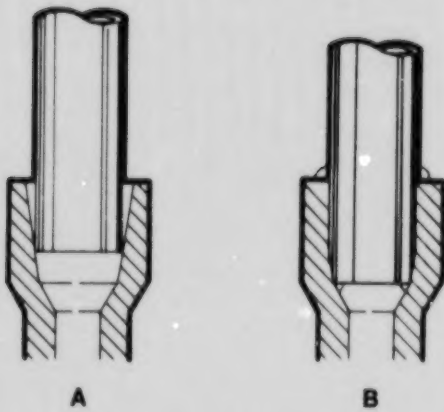


Fig. 12. (A) Exaggerated bell-mouthed interference fit; (B) tight fit develops single-piece weld. (Courtesy NIBCO Inc.)

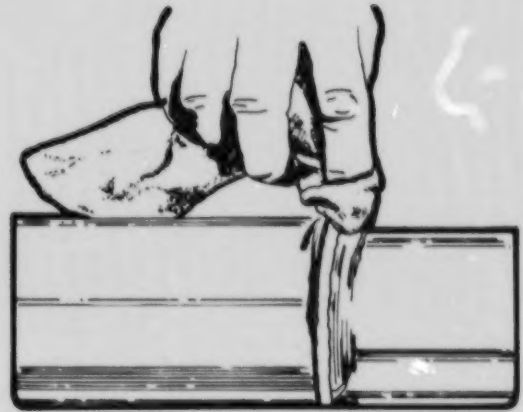


Fig. 13. Wipe off excess solvent. (Courtesy NIBCO Inc.)

Solvent cement is fast drying. It should be applied as quickly as possible, consistent with good workmanship. Apply a full, even coat of solvent to the surface of the pipe to the depth that will be taken into the fitting when it is seated. Then apply a full, even coat of solvent to the inside surface of the fitting, including the shoulder or seat at the bottom of the socket. Again, be careful not to leave a puddle at the bottom of the fitting. Recoat the pipe with a second uniform coat of solvent, including the end of the pipe.

Assembling the joint. Immediately after applying the last coat of solvent, insert the pipe into the fitting until it bottoms in the socket. **Twist the fitting about one-quarter of a turn** in one direction only. This will ensure an even distribution and absorption of the solvent. **Hold the joint firmly in place for about 10 seconds** (longer in cold weather) to allow the two surfaces to start bonding together. Remember the interference fit? If you release the joint too soon, the interference fit will tend to push the pipe back out of the fitting.

Check the ring of solvent that has been pushed out during the assembly and alignment. If the ring or bead does not go all the way around the joint, you have not used enough solvent, and the joint could leak.

Wipe off the excess solvent if the bead looks complete (fig. 13). Leave an even fillet all the way around the joint. Removing the excess solvent helps the joint cure faster.

Exercise

1. What is the advantage of designing a pneumatic system with a loop?

2. What causes a pressure drop between the point at which the air enters the system and the point at which it is used?
3. What is the maximum allowable pressure drop?
4. Why should the pipe not be installed inside a wall?
5. Why should the pipe have a 1 to 2 percent drop in the direction of flow?
6. Why is plastic pipe becoming more popular?
7. How are joints made in PVC and CPVC pipe?
8. What features does CPVC have that PVC does not?
9. What caused most of the pipe failures studied?
10. Why should solvent welding compounds not be opened until you are ready to use them?
11. Which tools should be used to cut plastic pipe?
12. Why should all ridges be removed from the pipe end before applying the solvent cement?
13. How far into the socket should the pipe fit before the solvent is applied?
14. What causes an interference fit?
15. Describe a proper solvent cement coating of the fitting and the pipe end.
16. Why should the fitting be twisted one-quarter of a turn after the pipe is inserted into the socket?
17. Why should the joint be held firmly in place for a short while, and not released too soon?
18. How can you check to make sure that enough solvent was used on the joint?
19. Why should the excess solvent be wiped off around the joint?

5

Copper Piping

Objectives: After completing this assignment, you will be able to explain the six steps in soldering a joint.

Copper pipe systems should be designed the same, and installed the same, as plastic pipe systems. However, the methods of joining copper pipe differ considerably from those for plastic pipe.

Either of three methods may be used to join copper pipe—the **compression joint**, the **flared joint**, or the **soldered joint**. The compression and flared joints are made mechanically and may be disconnected and rejoined at will. Although the soldered joint can be disconnected, it is considered a permanent joint.

Compression Joint

The simplest of the three joints is the compression joint. First, cut the tubing or pipe with a tubing cutter. (This procedure is explained later.) Remove the ridges from the inside of the pipe left by cutting. Remove burrs from the outside. Slip the compression nut over the end of the tubing with the threads facing the joint. Then slip the ferrule (compression ring) over the end of the tubing (see fig. 1). Insert the tubing into the fitting. Be sure it is butted against the seat of the fitting. Tighten the compression nut fingertight. Place one wrench on the fitting and another on the compression nut, and tighten snugly. Do not overtighten, or you will compress the compression ring too much, causing it to restrict the flow of air through the fitting.

Flared Joint

Cut the tubing with an appropriate tool. After cutting, ream and deburr the end. Then slip the tube nut over the tubing, with the threads facing the joint. Place the end of the tubing in the flaring tool. Be sure the end of the tubing does not extend more than 1/16 inch above the blocks of the flaring tool (fig. 2).

Tighten the blocks together to hold the tubing in place. Put a drop of oil on the end of the tubing. Tighten the cone over the end of the tubing, using steady, even turns. Stop when the flare is made. Do not compress the tubing. To do so will cause it to fail. Place the flared end against the ball seat of the fitting, and tighten the tubing nut securely (fig. 3). Do not overtighten the tubing nut. Use a wrench on the tubing nut and a backup wrench on the fitting. Using a backup wrench prevents twisting the tubing.

Soldered Joint

Soldering is a method of joining base metal by using a nonferrous filler metal. The filler metal is heated to a melting point below 800°F. Actually, most soldering is done at temperatures below 500°F, but 800°F is the temperature that separates soldering from brazing. The melting point of the base metal is somewhat higher than that of the filler metal. The filler metal is distributed between the parts to be joined by capillary action.

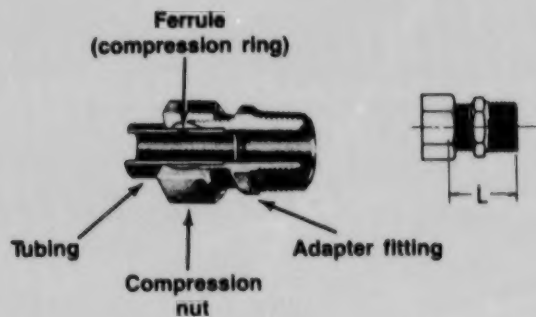


Fig. 1. This compression to a male thread fitting has three parts: compression nut, ferrule, and adaptor fitting. (Courtesy NIBCO Inc.)

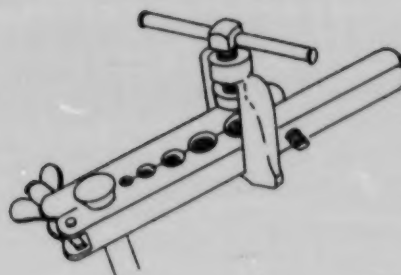


Fig. 2. Tubing should not extend more than 1/16 inch above the flaring blocks.

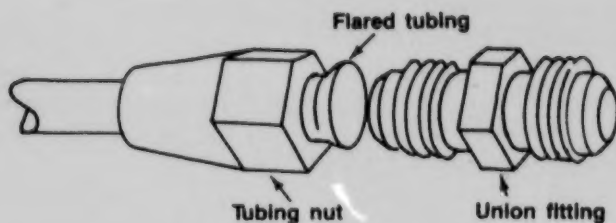


Fig. 3. Making a flared joint with a union fitting

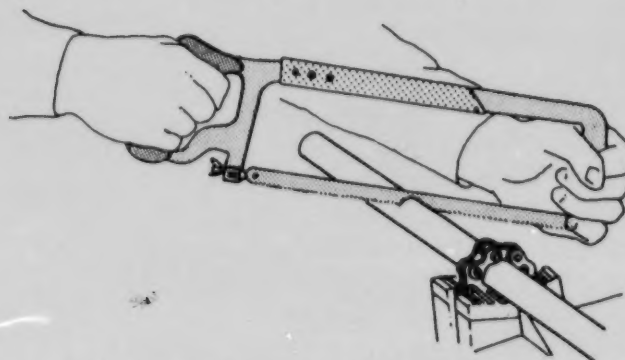


Fig. 4. Use a fine-toothed blade in the hacksaw. (Courtesy NIBCO Inc.)

There are six steps in soldering a joint. They will be discussed in the order in which they are performed.

Step 1: Cutting the tubing. The tubing can be cut with a hacksaw, abrasive wheel, or roller cutter. When using a hacksaw, use a fine-toothed blade that has at least three teeth in contact with the cutting edge at all times (fig. 4). Secure the tubing firmly in a vise. If a roller cutter is used, tighten the roller slowly to prevent upsetting (bending inward) the tubing more than is necessary (fig. 5).

When a hacksaw or abrasive wheel is used, remove the burrs and cutting drag from both the inside diameter and the outside diameter of the tubing (fig. 6). Half-round files do the job best, although scrapers and other devices also work well (fig. 7). When a flat metal reamer is used, take care that the tubing is not expanded or flared.

Step 2: Cleaning the surfaces. This step is important because the surfaces must be absolutely clean for the filler metal to wet the surfaces easily and evenly. With the tubing still secured by a vise, use a fine grit emery paper, steel wire brush, or steel wool to clean the end of the tubing (fig. 8). Remember, this is a **cleaning** operation. Do not remove any more material from the surface than necessary. If too much metal is removed, the capillary action will be adversely affected. Clean the tubing ends 1/4 to 1/2 inch more than the depth of the socket. This will allow some clean surface on which to melt and start the filler metal into the joint.

The socket should be cleaned with the same care as that used on the tubing end. Even though the fitting may look shiny and new, it should not have dust, grease, or fingerprints on it. It takes so little time to clean the socket that it is economical to do so. Remember, cleaning hundreds of fittings costs less than repairing one leak. Both the tubing and the sockets may be cleaned with emery paper, fitting brush, or steel wool.

If there are small dents or depressions in either of the surfaces to be joined, they should be cleaned. If there are large dents or depressions, the tubing should not be used.

Step 3: Fluxing. Although joints can be soldered without fluxing, it is seldom done.

This is because it is easier to solder using flux than to solder without it.

Fluxing has two purposes. First, it protects the base metal from oxidation during the heating process. Second, it breaks up oxides that form on the surface and floats them to the top and out of the joint. Fluxes are usually petroleum jelly containing a mild acid. The jelly protects the joint from oxidation, and the acid has a cleaning action.

Apply the flux as soon as possible after the surfaces have been cleaned. Apply it with a brush in a thin, even layer, using only enough flux to properly cover the surfaces to be joined (fig. 9). Excess flux only gets in the way of soldering and does not improve the joint.

Since flux is either wet or greasy, it will pick up dust and dirt. Do not allow fittings and tubing to lie around after they have been fluxed. Assemble the parts as soon as they have been cleaned and fluxed.

Step 4: Assembling. This is a particularly important step in joining copper tubing or pipe. An otherwise correctly performed job can be ruined if it is not assembled correctly.

The socket-type fittings are designed with enough depth to provide a good safety factor (fig. 10).

The tubing should be given proper support during assembly (fig. 11). It is critical in making good joints. You can make two mistakes that will result in faulty joints. First, failure to give proper support causes misalignment and improper dimension in the assembly. Misalignment will cause the tubing to be cocked in the fitting (fig. 12). This will affect the soldered joint by changing the space between the tubing and the fitting.

A second condition can be caused by improper support. Even though the tubing is in correct alignment, if the full weight of a long section of tubing is allowed to hang in the fitting, with no other support, it will be in close contact with the bottom side of the fitting while the space at the top side is almost doubled. When support is needed only during assembly, and not permanently, the tubing can be temporarily supported by wires or strings that can be removed once the joints are set (fig. 13).

Step 5: Heating. This is the most difficult of the six steps, and the one in

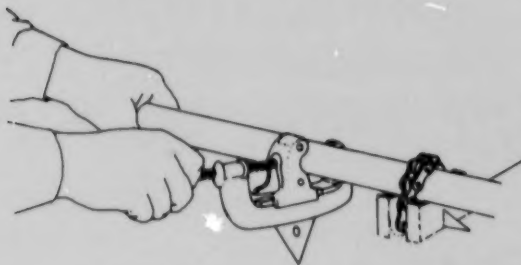


Fig. 5. Tighten roller slowly, and turn smoothly and evenly. (Courtesy NIBCO Inc.)



Fig. 6. A half-round file is best to remove burrs and cutting draw from tubing. (Courtesy NIBCO Inc.)

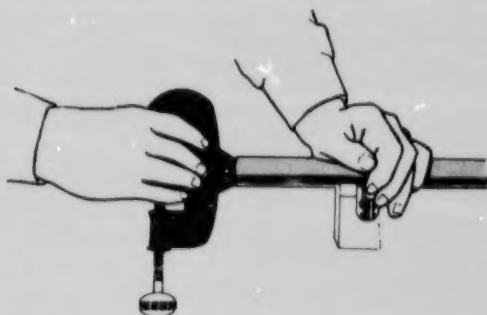


Fig. 7. Use care with a scraper that the tubing is not flared or expanded. (Courtesy NIBCO Inc.)



Fig. 8. Clean the tubing and socket with fine-grit emery cloth, steel wire brush, or steel wool. (Courtesy NIBCO Inc.)



Fig. 9. Apply a smooth, even, thin coat of flux to the tubing and the socket. (Courtesy NIBCO Inc.)



Fig. 10. A better joint is made by inserting the tubing until it butts against the seat.

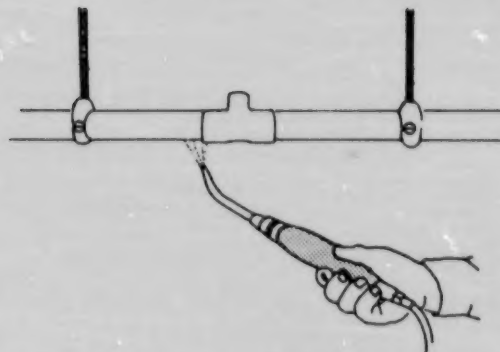


Fig. 11. Copper tubing should be properly supported. (Courtesy NIBCO Inc.)

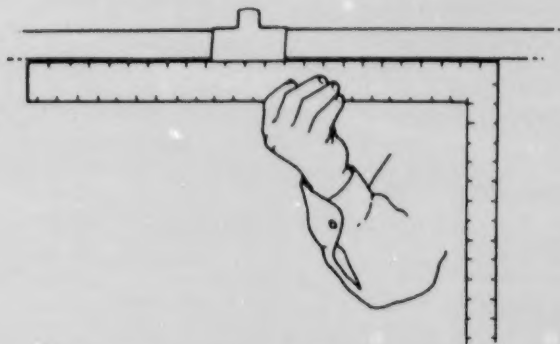


Fig. 12. Use a straightedge to check alignment of tubing; cocked joints fail. (Courtesy NIBCO Inc.)

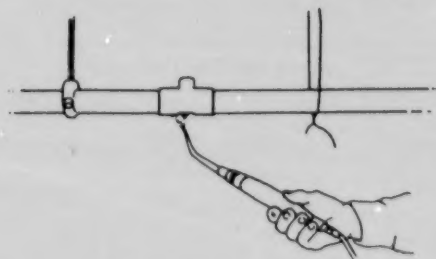


Fig. 13. Temporary support can be given during assembly by using wire or string. (Courtesy NIBCO Inc.)

which more mistakes are made. This is because heating is the only step that requires a sense of feel and skill in performing. All the other steps are simple, mechanical operations.

Two precautions should be exercised at this point. First, make sure the joint is properly prepared for soldering. Second, do not overheat. Heat the tubing and fitting evenly around the joint so the solder can be drawn into it evenly.

Heat can be controlled by the size of the flame used and by the length of time the flame is applied to the joint. Heat is better and more easily controlled by using a relatively small flame for a longer period of time. When soldering with a small flame has been mastered, you can graduate to larger flames.

The correct procedure for applying heat is as follows. First, heat the tubing before heating the fixture. Heat does not transfer well from the fitting to the pipe or tubing because of the small clearance insulating the two surfaces from each other. Apply the heat just beyond the end of the fitting for a short time. Then, move the flame back and forth to heat the fitting and the tubing alternately (fig. 14). Do not aim the flame directly into the corner formed by the tubing and the fitting. The flame should point from the fitting to the tubing. This will prevent the flame from burning the flux and oxidizing that small corner area where the solder must start into the space between the tubing and the fitting. The flame should be held so that the sharp point of the inner cone just touches the metal. This allows the heat to be evenly spread by the larger, outer envelope of flame.

Step 6: Applying the solder. The sixth step is applying the solder or filler metal. From time to time, as you are heating the joint, touch the edge of the solder to the joint area to see if it melts. **Do not melt the solder in the flame.** It should be melted only by contact with the joint. When the joint begins to melt the solder, remove the flame (fig. 15). Apply the solder to the joint at one or two points. Feed the solder into the joint with a gentle push until a ring of solder appears at the end of the fitting.

If an electric solder gun is used, hold it on the fitting with the solder at the lip of the joint until the solder begins to melt (fig. 16). Then after the socket has filled,

remove the grips. Excess solder should be removed immediately with a small brush or a wiping cloth (fig. 17).

Exercise

1. Which of the three types of joints may be connected and disconnected at will?
2. What should be used to cut copper tubing?
3. How should the cut end of the tubing be treated before slipping the compression nut over it?
4. How far should the tubing be inserted into the fitting?
5. Why should you be careful not to over-tighten the compression nut?
6. What is the maximum amount the tubing should extend out of the flaring tool?
7. Describe the manner in which the cone is tightened over the end of the tubing.
8. Why is it important not to compress the tubing?
9. Why should a backup wrench be used when making the flared connection?
10. Most soldering is done below what temperature?
11. How does the melting temperature of the solder compare with that of the material being soldered?
12. What process distributes the melted solder between the parts being soldered?
13. What is the best tool to use to remove burrs and cutting drag from both the inside diameter and the outside diameter of the tubing?
14. Why is it important that the surfaces to be soldered be absolutely clean?
15. Why should as little material as possible be removed from the end of the tubing during the cleaning process?
16. How much of the end of the tubing should be cleaned?
17. What should be done with tubing that has large dents or depressions in it?
18. What two functions are served by flux?
19. Describe how the flux is applied on the tubing.
20. Why is it important that the tubing and fittings be assembled as soon as possible after they have been cleaned and fluxed?
21. Why will misalignment cause the joint to fail?



Fig. 14. First apply heat to the tubing, then alternately heat the fitting and tubing. (Courtesy NIBCO Inc.)

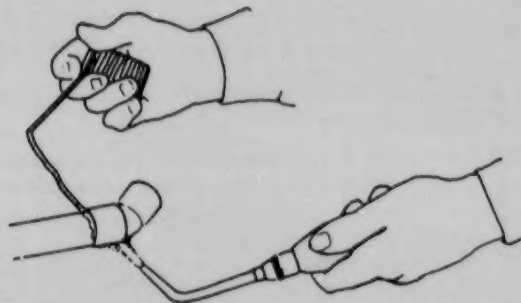


Fig. 15. When solder begins to melt, remove the flame. Apply solder until ring forms around the socket. (Courtesy NIBCO Inc.)

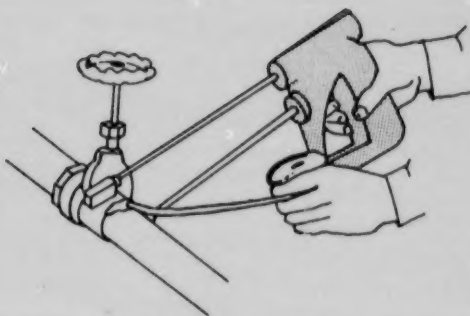


Fig. 16. Hold the electric solder gun on the socket until cup fills. (Courtesy NIBCO Inc.)



Fig. 17. Remove excess solder with wiping cloth while it is plastic. (Courtesy NIBCO Inc.)

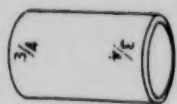


Fig. 18. Coupling with stop, copper to copper (Courtesy NIBCO Inc.)



Fig. 19. Drain coupling, copper to copper (Courtesy NIBCO Inc.)

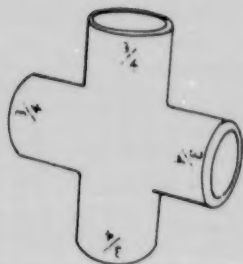


Fig. 20. Cross, copper to copper to copper to copper (Courtesy NIBCO Inc.)

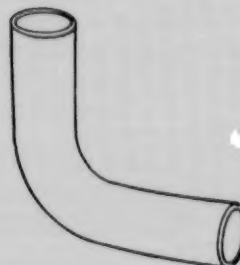


Fig. 21. 90 baseboard ell, copper to copper (Courtesy NIBCO Inc.)

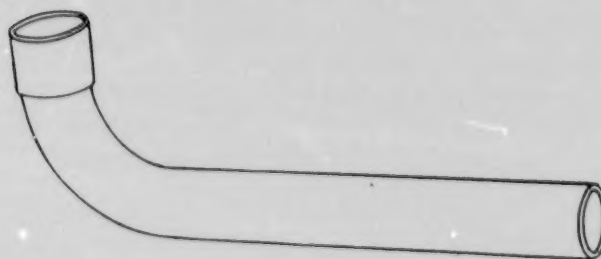


Fig. 22. 90 fitting ell, fixture to copper (Courtesy NIBCO Inc.)

22. Why are more mistakes made in the heating step of joining metal than in all the other steps?
23. What are two precautions to take when heating?
24. Why is it important that the tubing and fitting be evenly heated?
25. What are two methods of controlling heat?
26. What is the correct method of applying heat to the tubing and fitting?
27. How should the flame be held?
28. How should the solder be melted?
29. When should the flame be removed from the joint?
30. When should the electric solder gun be removed from the joint?

6

Conditioning Compressed Air Systems

Objectives: After completing this assignment, you will be able to—

1. explain how moisture enters the pneumatic system;
 2. explain how driers operate;
 3. explain how filters operate;
 4. explain how regulators operate; and
 5. explain how lubricators operate.
-

Moisture presents the greatest threat to the pneumatic system, and it is ever-present. It is introduced into the system along with the air. The amount of moisture introduced depends on the relative humidity in the air. As the air is compressed, the moisture in it condenses. The reason for the condensation is simple. A given volume of space can absorb only a given amount of moisture. As the amount of air in that given volume is increased, so is the amount of moisture. For example, a cubic foot of space will hold a given amount of moisture at a given temperature. When ten times that amount of air is compressed into the cubic foot of space, so is ten times the amount of moisture. The excess moisture cannot be contained in the air. It condenses and forms water.

Since cold air holds less moisture than warm air, an after cooler is located next to the compressor. The cooler air flows through a separator, which condenses most of the moisture and removes it. In-line driers and filters are used to further treat the air before it reaches the working parts of the system.

Driers

Three types of driers are used to remove moisture: absorption driers, adsorption driers, and low-temperature driers.

Absorption Drier. Absorption drying is a chemical process in which the compressed air flows through a container with a drying agent (fig. 1). The air usually flows in at the bottom and out through the top. A drain is located at the bottom. As the air flows through the drying agent, the moisture is absorbed by the drying agent. This forms a chemical compound, which must be regularly removed from the drier. In time, the drying agent will lose its effectiveness and must be removed.

The drying agent will also filter out lubricating oils and oil vapors. For this reason, a filter must be installed in front of the drier. This extends the life of the drier and permits the lubricant to be recycled.

Adsorption Drier. Adsorption drying is a physical process. A desiccant, or drying agent, collects or adsorbs the water on its surfaces (fig. 2). The desiccant is in a granular form, which presents a tremendous amount of surface for adsorption. The desiccant is made of silicon dioxide and is usually called a "gel."

In time, the desiccant becomes saturated with moisture. When this occurs, hot, dry air can be pumped through the drier and vented through a waste vent to the atmosphere. This removes the moisture from the desiccant, and it can be used again.

Low-Temperature Drier. Low-temperature drying is a mechanical method

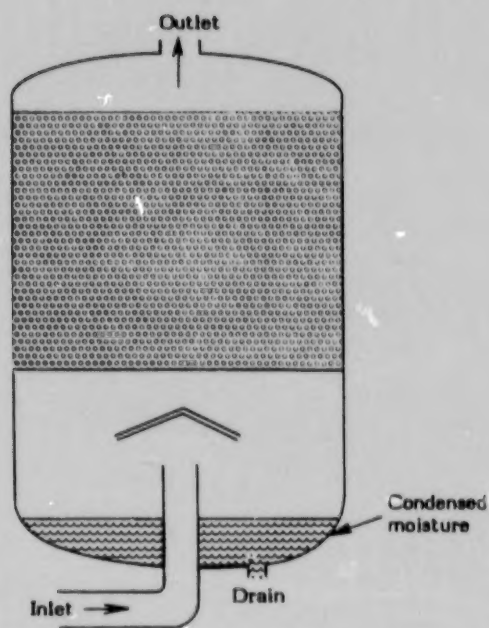


Fig. 1. Absorption drier

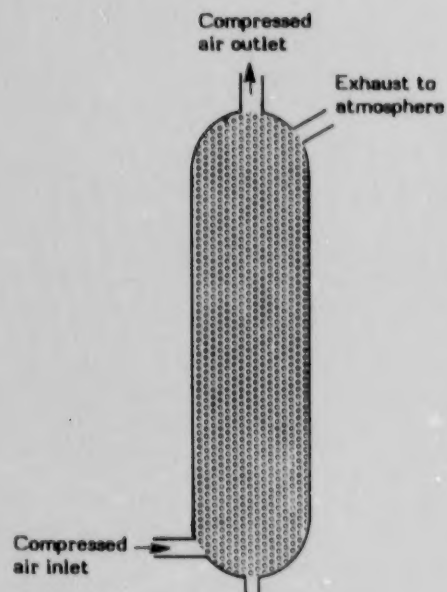


Fig. 2. Adsorption drier

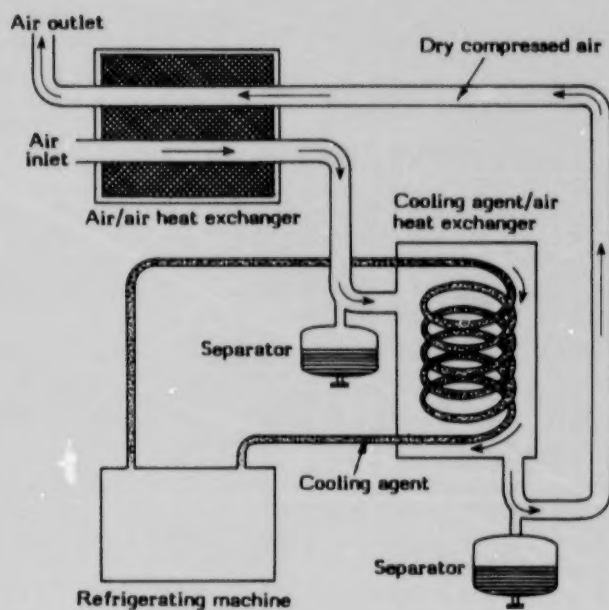


Fig. 3. Low-temperature drier

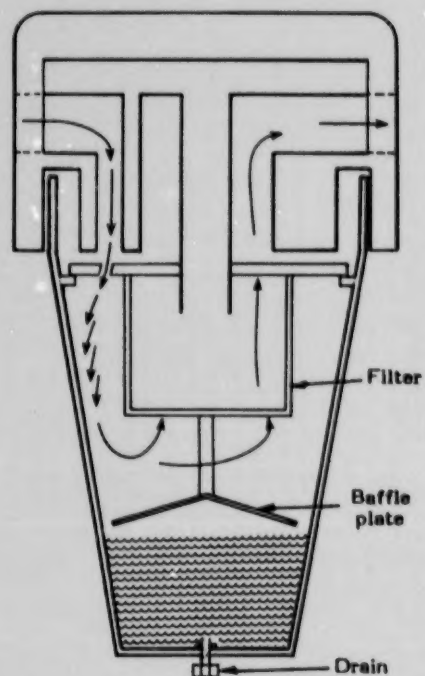


Fig. 4. Air filter with manual drain

of removing moisture from compressed air (fig. 3). A refrigeration process is used to cool the air to its dew point (point at which the moisture condenses). The moisture condenses and flows to a separator where it is removed. Figure 3 shows the air as it first flows through an air/air heat exchanger. Cool air in the exchanger cools the piping flowing through it. Air in the piping is, in turn, cooled by the piping. It then flows through a separator where some of the moisture is condensed from the initial cooling. The air flows through the refrigerant/heat exchanger. As the air flows through this exchanger, it is cooled to its dew point. Another separator is located at this point to collect and remove all the moisture that is condensed as a result of the cooling.

Air Filters

An air filter (fig. 4) removes noncompressibles (dirt, rust particles, etc.) as well as water droplets from the compressed air. In operation, air flows in the filter and is directed downward. It flows through a baffle plate. The baffle plate is designed to impart a swirling motion to the air. This swirling motion tends to throw the heavier particles and droplets of water outward and downward. These particles and droplets fall below a second baffle plate that deflects the incoming air upward and out without disturbing the dirt and droplets of water underneath it. The air is further filtered by a porous filter element as it flows out the upper section of the filter housing. The filter may be equipped with a drain plug for manual filtering or an automatic drain (fig. 5).

A second type of filter uses a filter element to remove particles of dirt and droplets of water and oil. The element is made of a porous material that will filter particles that are 0.01 micron or larger. In operation, air flows in between the filter element and the filter housing. It then flows through the walls of the filter. Particles too large to flow through the filter are separated from the airflow and fall to the bottom of the filter bowl. The air flows up and out the outlet on the side of the filter housing.

Pressure Regulators

Pressure regulators keep the operating pressure constant even though the compressor pressure and the air consumption rate may fluctuate (go up and down). In order to do this, the compressor pressure must always be higher than the operating pressure. Figure 6 shows a typical pressure regulator. This is a diaphragm regulator in which the operating pressure operates on one side of the diaphragm and the spring pressure acts against the outlet pressure side of the diaphragm. An adjusting screw allows the spring pressure to be increased or decreased as needed.

In operation, as the operating pressure increases, the diaphragm moves downward. This movement also moves the valve disc downward. This will either close the valve or partially close it, according to need. The closing of the valve stops incoming air and reduces the operating pressure. As the operating pressure drops, the diaphragm will begin to move upward, opening the valve disc and allowing more air to flow through it. This increases the operating pressure. Thus, the pressure valve regulates the pressure, keeping it within the correct operating pressures.

Lubricators

Pneumatic systems are lubricated for two reasons. First, lubrication reduces friction and wear on the working parts of the system. Second, lubrication protects the system from corrosion. Most lubricating systems operate on the venturi principle. A venturi is a device used to create a partial vacuum. It is a restriction built into the piping system (fig. 7). Its purpose is to speed up the flow of air through it by making the same volume of air flow through an area of smaller circumference than the piping. This creates a low-pressure area or partial vacuum. Figure 8 shows that the pressure at point B is less than that at point A. As the liquid in the tube rises at point B, the liquid level drops at point A. This is caused by the difference between the pressure on the liquid at points B and A.

Figure 8 shows a typical lubricator. As air flows through the lubricator, it

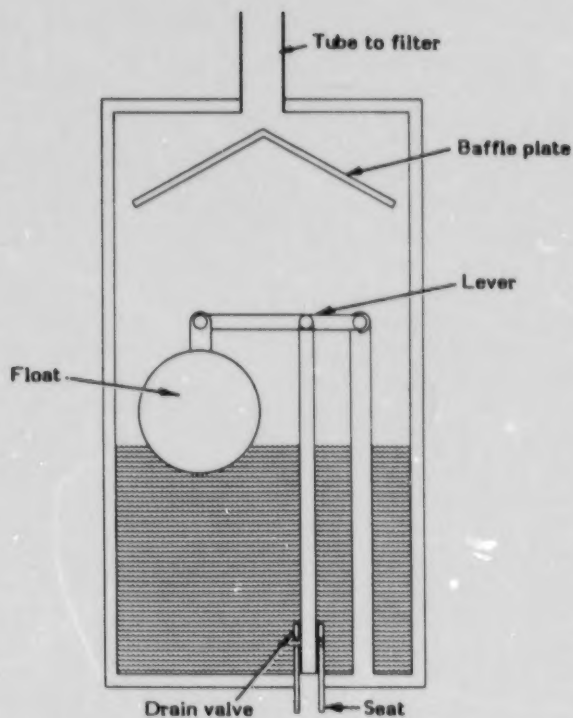


Fig. 5. Water separator with automatic drain

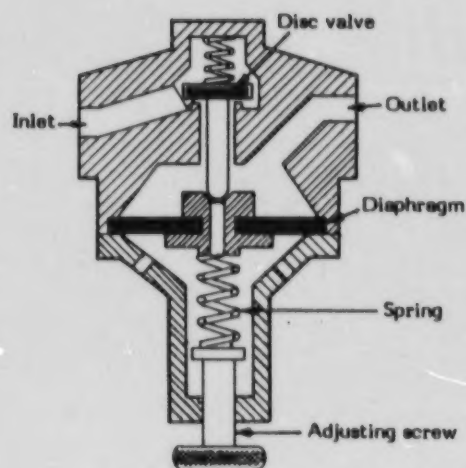


Fig. 6. Diaphragm pressure regulator

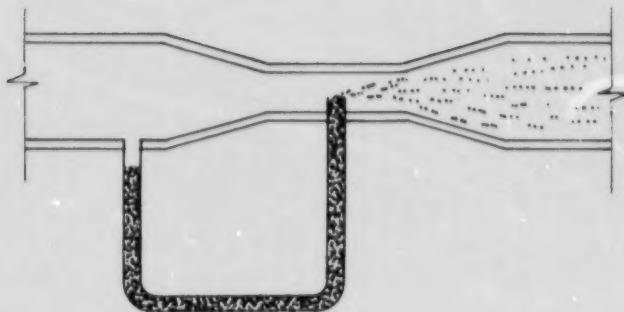


Fig. 7. A venturi increases air flow speed, which creates a low-pressure area.

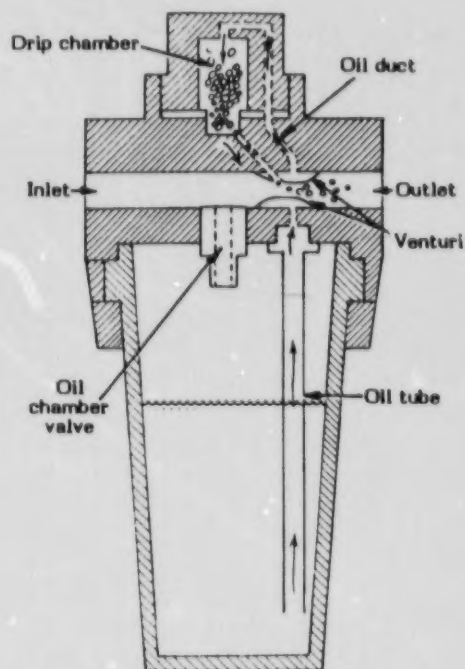


Fig. 8. Operation of a lubricator

encounters the venturi. Air movement through the venturi is increased, creating a low-pressure area. Air pressure on the lubricating fluid surface in front of the venturi is greater than that on the oil passage at the venturi. This forces the oil up through the oil passage. Air flowing past the oil passage vaporizes the oil and carries it through the pneumatic system. Adjusting screws are located so that the flow of air can be regulated, thus regulating the amount of oil entering the system.

Exercise

1. How does moisture get into the pneumatic system?
2. What causes moisture to condense out of compressed air?
3. Why is an after cooler located next to the compressor of a pneumatic system?
4. What kind of process is absorption drying?
5. Why must the drying agent of an absorption drier be changed regularly?
6. Why is a filter placed in front of a drier?
7. What kind of process is adsorption drying?
8. How does the adsorption drier operate?
9. In what form is the desiccant available?
10. How is a saturated desiccant renewed?
11. How does a low-temperature drier remove moisture?
12. What are noncompressibles?
13. What is the effect of the swirling motion imparted to the incoming air by the baffle plate?
14. What is the function of the lower baffle plate?
15. What is the smallest size particles that the porous filter element will remove?
16. What is the function of the pressure regulator?
17. Which forces operate on each side of the diaphragm?
18. What are the two functions of the lubricator?
19. On what principle do most lubricating systems operate?
20. What condition does the venturi create when the air is forced through it?
21. What results from the low-pressure area being created?

7

Pressure Gauges and Volume Meters

Objectives: After completing this assignment, you will be able to—

1. explain the importance of the shape of a Bourdon element;
 2. explain how a Bourdon tube works;
 3. describe the advantages of the Bourdon elements; and
 4. explain how a nutating piston meter works.
-

Pressure gauges are used in pneumatic systems to measure system pressure so that the operator can maintain efficient and safe operating pressures.

Bourdon Gauges

Bourdon gauges use elements that are made of a "C," spiral, or helical shape (fig. 1). One end of the element is stationary, and the other is free to move. As pressure builds up inside the element, it attempts to straighten out. If the elastic limit of the element is not reached, the element will return to its original position when the pressure is released. The free end motion, or "tip travel," is directly proportional to the amount of pressure inside the element.

The **C-tube** is the most commonly used Bourdon element. It is easier to manufacture in uniform quality and large quantity. It also occupies less space in both depth and width than the spiral and helical units.

The advantage of the **spiral and helical** units is that they provide much greater movement, or tip travel. In many instances, the smaller motion of the C-tube is increased by using gears or levers (fig. 1). C-tubes are stable and rugged. They can flex about the set point indefinitely, yet adjust to pressure changes with microscopic accuracy. Spiral and helical Bourdon tubes provide greater tip travel for a given pres-

sure. This permits the indicator or hand or pen arm to be attached directly to the free end of the tube. Another advantage these tubes have over the C-tube is that greater accuracy is obtained through the direct connection than is possible through levers and gears. There is less lost motion and friction to interfere with accurate gauging of pressures.

Bourdon tubes can be used to measure the difference between two pressures. The pressure differential is measured by connecting two Bourdon tubes that receive pressure from two different sources. In figure 2, the first tube (on the right) is mounted 180° from the first tube. The pressures cause the two tubes to pull against each other. The stationary end of the second tube is mounted on a pivot with a lever connected to the traveling tip of the first tube. The traveling tip of the second tube has an indicator hand that registers the difference between the pressures of the two Bourdon tubes.

Volume Meters

Volume meters are displacement meters that use the energy from the flowing air to operate the indicating mechanism. The following describes the operation of a **nutating piston meter**. In operation, air passes through a fixed-volume measuring chamber

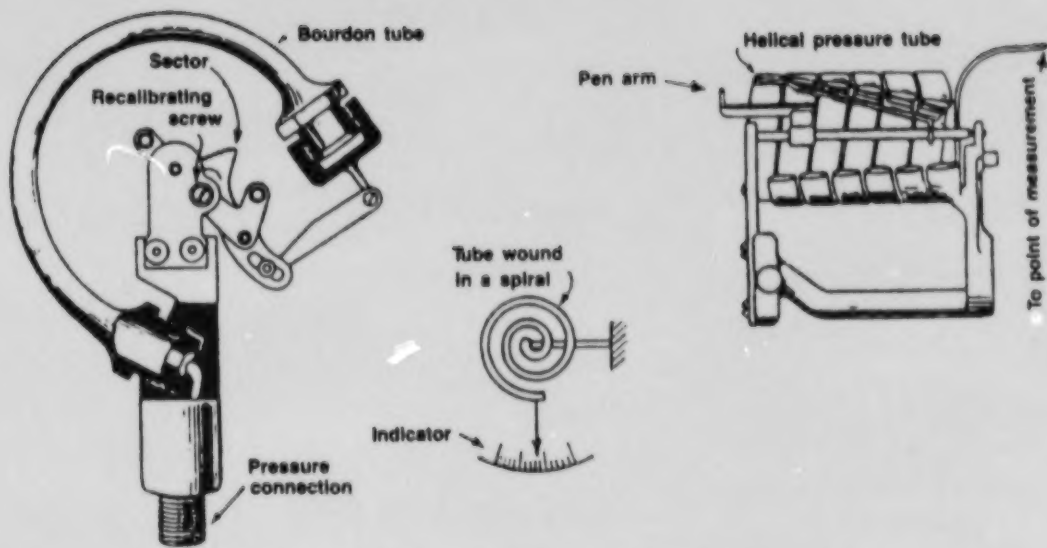


Fig. 1. Three basic types of Bourdon tubes or elements

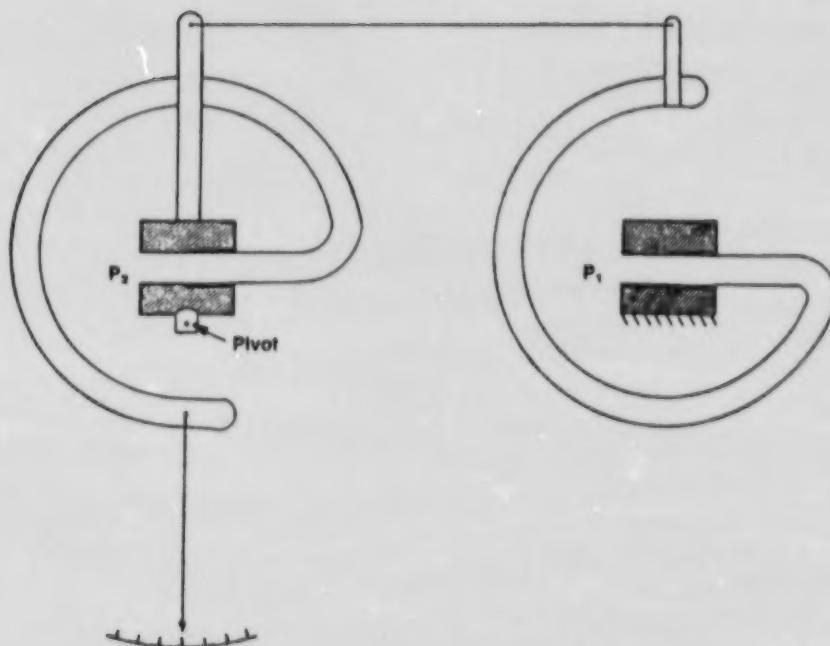


Fig. 2. Bourdon tubes arranged to measure differential pressure



Fig. 3. Nutating piston positive-displacement meter
(Courtesy American Motor Controls, Inc.)

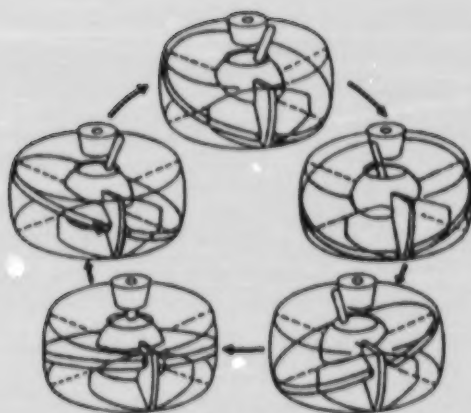


Fig. 4. Operation of the nutating disk

divided into upper and lower compartments by a piston that resembles a disk. As one compartment is being filled, the other compartment is being emptied. As the air passes through the compartments, it causes the disk to roll around in the chamber.

As shown in figure 3, the piston is limited in its motion by (1) a ball-like center section that rides in a socket and prevents vertical motion of the piston, (2) a disk that contains a single deep and narrow slot into which a rigid separator plate fits that prevents free motion, and (3) a pin that protrudes from the ball and rides against a fixed conical surface to force the disk to assume a cocked position at all times.

Look at the bottom left-hand drawing in figure 4. At this position of the disk, air from a previous cycle is trapped under the right side of the disk and only goes out of the discharge port on the right side of the rigid separator. Air from upstream entering the inlet port (left side of the rigid separator) flows under the disk and tends to lift it. The disk responds to this lifting force by squeezing air out through the discharge.

At the upper left-hand drawing in figure 4, you can see that air is also flowing above the disk. As you move to the upper center drawing, it is clear that most of the

air trapped from the previous cycle has now been forced out into the outlet. Also, you can see, in the upper right-hand drawing, that another quantity of air is about to be trapped below the disk. Air is now free to travel in the cavity above the disk and begin a new cycle.

Exercise

1. What is the importance of the shape of a Bourdon tube?
2. How is tip travel related to the pressure inside the element?
3. Why is the C-tube the most commonly used Bourdon element?
4. What is the advantage of the spiral and helical units?
5. How can the motion of the C-tube be increased?
6. Why are the spiral and helical tubes with the direct connections more accurate than C-tubes?
7. How are two Bourdon tubes arranged so that they can measure the difference between two pressures?
8. What powers a nutating piston meter?
9. What are three major parts of a nutating piston meter?
10. Where does the air flow through the nutating piston meter?

8

Pneumatic Working Elements

Objectives: After completing this assignment, you will be able to—

1. explain how pneumatic cylinders and motors are constructed; and
 2. explain how the pneumatic cylinders and motors operate.
-

Pneumatic Cylinders

Cylinders are among the devices used to convert pneumatic power back into mechanical energy. Two types of cylinders are used for this purpose: the piston cylinder and the vane cylinder. The **piston cylinder** is used to impart a straight back-and-forth movement. The **vane cylinder** gives a rotary back-and-forth movement.

Piston Cylinders. Several types of piston cylinders are used. The **single-acting cylinder** has a single port that is used both to allow the air to enter the cylinder and to discharge it from the cylinder. Obviously, air is admitted to only one side of the piston (fig. 1). This means that air pressure is exerted in only one direction. The return of the piston to its original position is done either with a return spring or by gravity. Piston seals around the circumference of the piston prevent air from leaking from the air compartment side of the cylinder. An air vent in the air chamber opposite the compression chamber prevents a buildup of air pressure or the creation of a vacuum. Either condition would affect the efficiency and operation of the cylinder.

A **diaphragm cylinder** (fig. 2) is a modification of the single-acting cylinder. The rod and its seal are replaced by a diaphragm that seals the chamber and also holds the

piston. The piston is thin material attached to the diaphragm. It is held in place by flanges located on each side of the piston. A diaphragm cylinder is used in situations where only small piston movement is required.

Pneumatic pressure applied under the diaphragm moves the diaphragm and piston outward. When pressure is released, tension from the diaphragm returns it to its resting point.

A **rolling diaphragm cylinder** (fig. 3) is another application of a single-acting cylinder. A rolled up diaphragm is located between the air chamber and the piston. As pneumatic pressure is applied, the piston is moved outward. As the piston moves outward, the diaphragm unrolls along the inner cylinder wall. The rolling diaphragm permits a larger stroke than that of a regular single-acting cylinder. It also reduces friction between the piston and the cylinder.

The **double-acting cylinder** (fig. 4) has two ports through which pneumatic pressure is supplied to the cylinder and from which the pressure is discharged from the cylinder. Pneumatic pressure is forced into one side of the cylinder to extend the piston. As the piston moves outward, the air on the opposite side of the piston flows out and is vented into the atmosphere. At the end of its stroke, the piston is moved in the

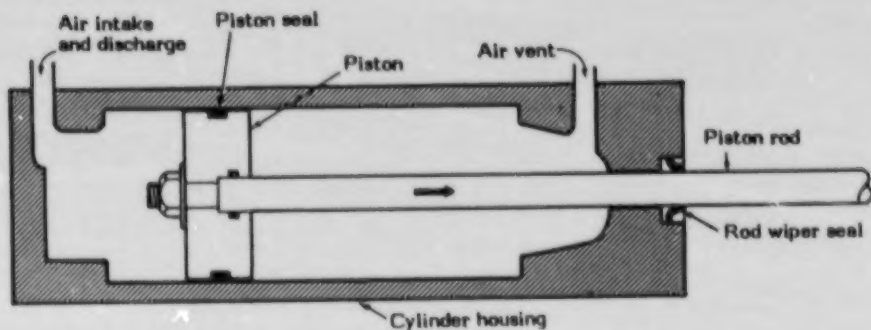


Fig. 1. Single-acting cylinder exerts pneumatic pressure in one direction only.

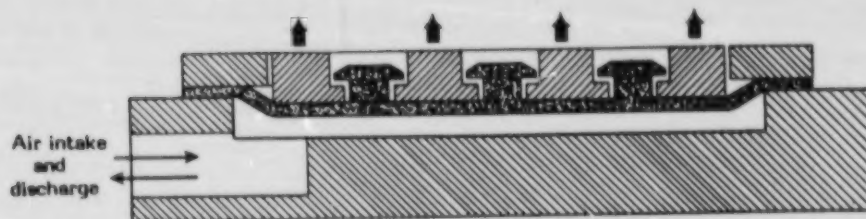


Fig. 2. Diaphragm cylinder has limited piston movement.

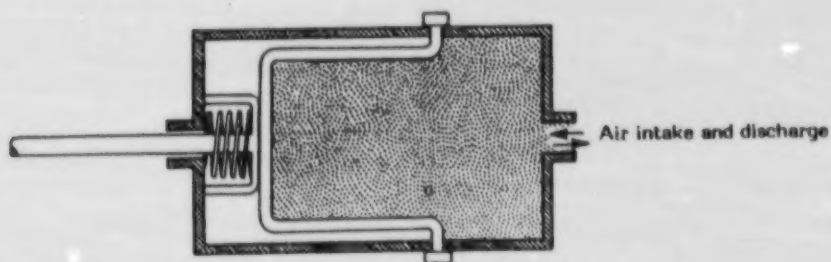


Fig. 3. Rolling diaphragm cylinder permits greater piston travel.

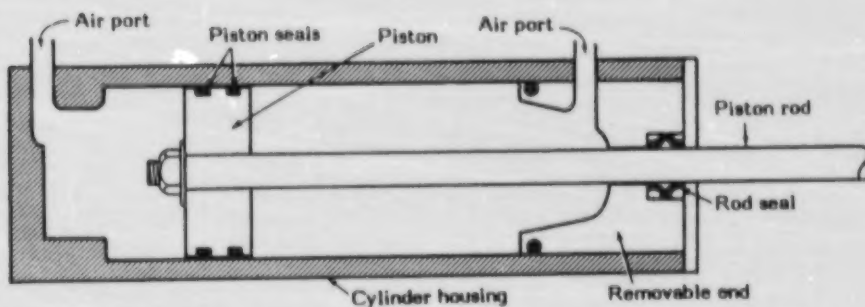


Fig. 4. Double-acting cylinder exerts pneumatic force in both directions.

opposite direction by admitting pneumatic pressure to the opposite side and reversing the process.

Since pressure is exerted in the compartment through which the piston operates, a second seal is required to prevent the air from leaking out around the piston rod.

An **air cushion** (fig. 5) is sometimes used in cylinders to protect them from the impact of sudden stops. This cushion is a method of slowing the piston before it reaches the end of its stroke. This is done by providing a cushion air chamber with a valve-controlled exhaust vent. As the piston approaches the end of the stroke, it traps air in the cushion air chamber. The air is compressed, providing increasingly greater resistance as the piston moves closer to the end of its stroke. Air pressure overcomes the valve spring pressure and opens the exhaust valve, allowing the air to flow slowly from the cushion air chamber. The piston movement is stopped, and its movement is reversed.

A **double-ended piston rod** (fig. 6) has a rod extending from each end of the cylinder. A double-ended piston rod is also a double-acting cylinder. Because it has bearings at each end of the cylinder for the rod, a double-ended piston rod cylinder is a better design than a single-ended piston rod cylinder.

Vane Cylinders. Vane cylinders do not have the straight back-and-forth motion of piston cylinders. Rather, the vane in the cylinder rotates from side to side. The vane cylinder (fig. 7) has a fixed vane on the cylinder wall. Its outer edge forms a seal with the rotating shaft. A second vane is attached to the shaft and forms a seal with the inside cylinder surfaces. This divides the interior of the cylinder into two compartments. A port on each side of the fixed vane admits and discharges air. A second port can be used in the same manner as the ones in the piston cylinder to prevent damage from the impact of sudden stops.

In operation, an arm is attached to the protruding end of the shaft. This arm is attached to the device that does the work. Because it is a double-acting cylinder, air flows out one side of the cylinder as air is forced into the other side. This rotates the shaft and arm. The procedure is reversed to

cause the arm to rotate in the opposite direction.

Pneumatic Motors

Motors are a second type of device used to convert pneumatic power back into mechanical power. Pneumatic motors are of the gear type or vane type.

Gear Motors. Gear motors (fig. 8) consist of a housing and two gears of equal size. The teeth of the gears form a seal at the inside wall of the motor housing and at the point at which the two gears mesh. This separates the intake chamber from the discharge chamber.

Figure 8 shows the operation of the gear motor. As air is forced into the inlet of the motor under pressure, the teeth of the motor are forced to rotate away from the intake port. The shaft to one of the gears is a drive shaft. As the gears rotate, the drive shaft rotates, powering the working element attached to it. The meshing teeth of the gears force the air into the compartment near the discharge port. This port vents the air into the atmosphere. Thus, the intake side is under compression while the discharge side operates at atmospheric pressure. It is the difference between the high pressure entering on the intake side and the low pressure on the discharge side that provides the torque for the motor.

Vane Motors. Vane motors (fig. 9) consist of a circular housing, a rotating cylinder, and sliding vanes carried in slots in the cylinder. The housing, while circular, is somewhat larger than the circumference of the rotating cylinder. The shaft on which the cylinder rotates is offset in the housing so that the cylinder almost touches the cylinder wall on one side while it is a considerable distance from the wall on the other side. The vanes in the cylinder remain in contact with the cylinder wall regardless of their positions. They are held against the wall by centrifugal force.

On the intake side of the chamber, air is forced into the space between the vanes under pressure. It is held between the vanes. Since there is more volume on the side with the extended vanes, there is also more pressure. This causes the rotor

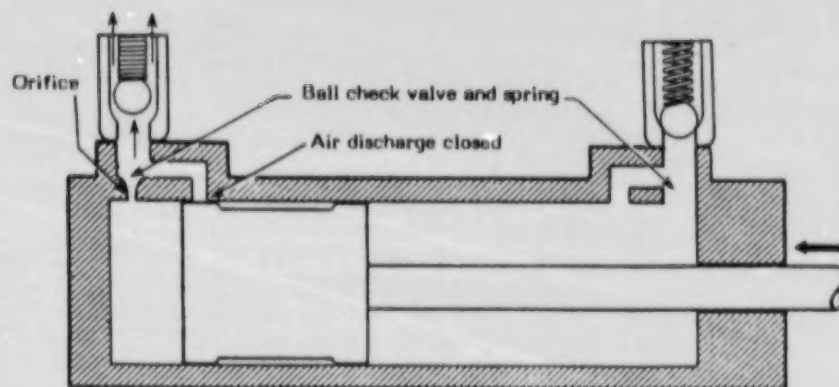


Fig. 5. Air chamber cushions the sudden stop of the piston.

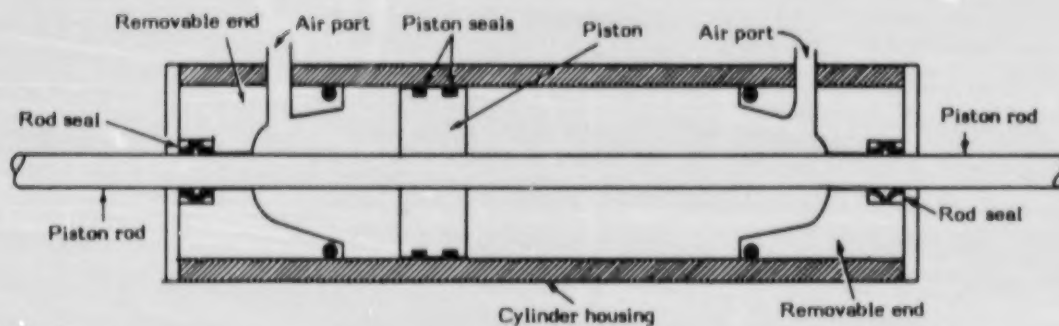


Fig. 6. Double-ended piston rod cylinder does work on both ends.

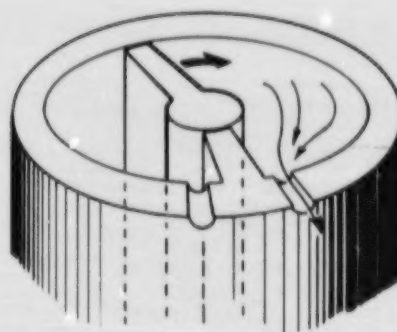


Fig. 7. Vane in vane cylinders rotate from side to side.

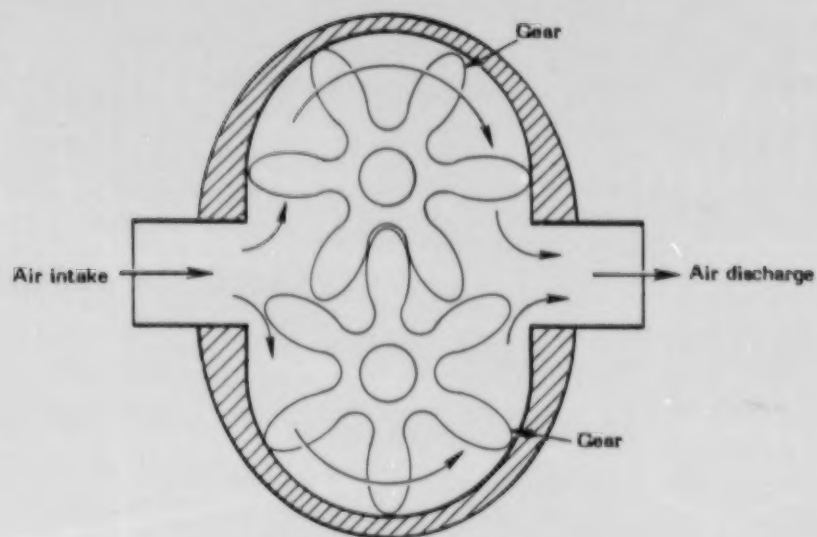


Fig. 8. Gear-type motor

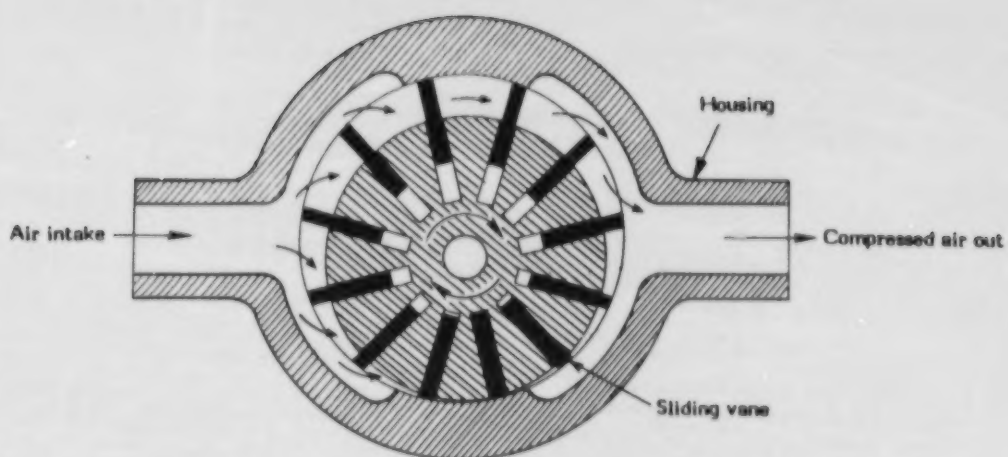


Fig. 9. Sliding vane motor

(cylinder) to rotate in that direction. As the vanes begin to move back in towards the rotor, air is forced through the discharge port, which operates at atmospheric pressure. Air is vented through the exhaust port into the atmosphere.

Exercise

1. What function does the piston cylinder serve?
2. How many ports are used on a single-acting cylinder?
3. What returns the piston of a single-acting cylinder to its original position after pneumatic pressure moves it forward?
4. What is the purpose of the vent in the air chamber opposite the compression chamber?
5. Which parts of a single-acting cylinder does a diaphragm replace?
6. In which situations would a diaphragm cylinder be used?
7. What are the advantages of a rolling diaphragm cylinder?
8. What is the function of each of the ports of a double-acting cylinder?
9. Where is the air from the cylinder discharged to?
10. Why are air cushions used in pneumatic cylinders?
11. What controls the rate at which the air is vented from the air cushion chamber?
12. What distinguishes a double-ended piston rod?
13. What makes a double-ended piston rod cylinder a better design than a single-ended piston rod cylinder?
14. What kind of motion does a vane cylinder impart?
15. With which part does the stationary vane seal?
16. With which part does the rotating vane seal?
17. How many ports does a vane cylinder require?
18. Of which parts does a gear motor consist?
19. Where is the gear motor sealed?
20. Which factors provide the torque for the gear motor?
21. Of which parts does a vane motor consist?
22. Where is the cylinder shaft located in relation to the circular housing?
23. What holds the vanes against the walls when the vane motor is operating?
24. What causes the vane motor to rotate in the correct direction rather than backwards?
25. What happens to the air trapped between the vanes when the vanes begin to move back in towards the rotor (cylinder)?

9

Pneumatic Valves

Objectives: After completing this assignment, you will be able to—

1. explain the functions of pressure control valves and directional valves; and
 2. explain how the various valves operate.
-

Valves control the functions of pneumatic systems. They control the pressure throughout the system, direct the air to the proper circuits, and regulate the volume of air to each circuit. Two different types of valves are used to perform these functions: (1) pressure control valves and (2) directional control valves.

Pressure Control Valves

Pressure control valves limit the pressure in a pneumatic system, unload the excess pressure from the pump when proper pressure for the system has been exceeded, and regulate the pressure at which air enters a circuit.

Relief valves are used to protect the pneumatic system when excessive pressures develop. The sole function of a relief valve is to prevent the pneumatic system from developing pressure above a given amount.

A **simple relief valve** (fig. 1) has a valve, a seat, and a spring with calibrated tension. As long as the system pressure is within the safe operating range, the spring tension overcomes the pressure from the pneumatic system and the valve remains closed (fig. 1). However, when the pressure becomes greater than the safe operating range, pneumatic pressure overcomes the spring tension. This forces the valve open and allows the air to vent to the atmosphere. When the pressure drops again to

the safe operating range, the spring tension will overcome the pneumatic pressure and close the valve again.

Some relief valves are equipped with an adjustment screw (fig. 2). The screw can be tightened down to increase the tension and raise the pneumatic pressure level required to raise the valve, or it can be loosened to lower the pressure level at which the pneumatic pressure can raise the valve. While most relief valves use a ball, some are made with valves shaped like buttons, small cones, or disks.

A **pilot-operated relief valve** is used when the valve must handle large volumes and when there must be little difference between the point at which the valve opens and the point at which it closes. The pilot valve controls the amount of pressure on the backside of a relief valve. When the pilot valve opens, it allows the pneumatic pressure to overcome the spring tension of the relief valve and allow it to open. When the pneumatic pressure becomes less than that of the pilot setting, the relief valve will close.

Pressure-reducing valves are required when the main circuit delivers high or fluctuating pressures even though a branch of the circuit requires a lower constant pressure. Figure 3 shows a typical pressure-reducing valve when the pressure is balanced and the valve is not operating. It is in an open position during this time, and the

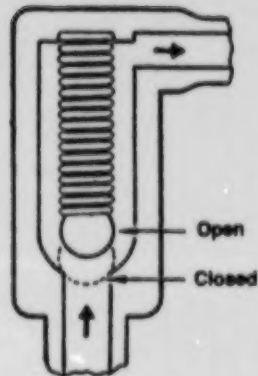


Fig. 1. Spring pressure must be overcome to unseat the valve of a simple relief valve.

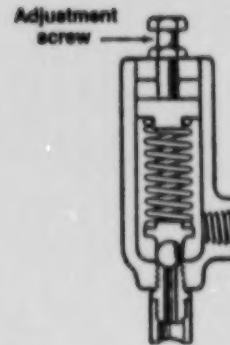


Fig. 2. Relief valve pressure level can be adjusted with an adjustment screw.

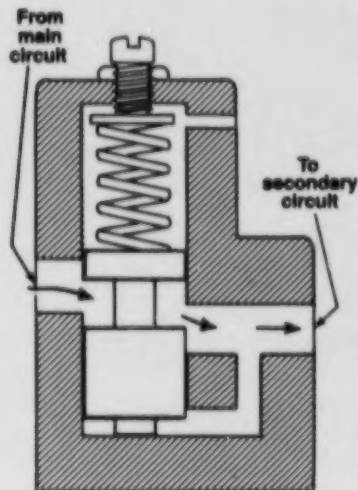


Fig. 3. Pressure-reducing valve does not work when pressure is balanced.

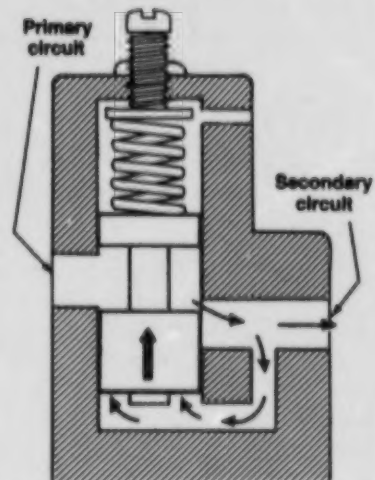


Fig. 4. Spring tension above the valve sets the volume of air that passes through the valve.

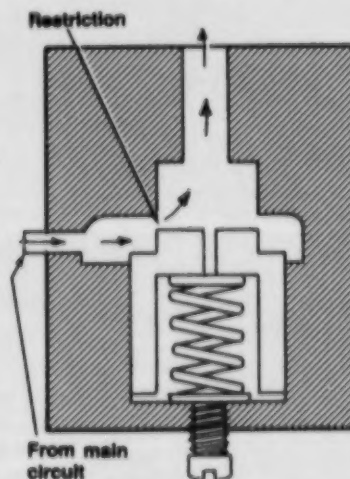


Fig. 5. The secondary circuit pressure is equal to the spring pressure.

air flows freely. Figure 4 shows how the valve reacts to an increase in pressure. The increased pressure in the secondary circuit is routed to a chamber below the pressure-reducing valve. This causes the valve to lift up, partially closing the port in the secondary circuit. The amount of air allowed to pass is determined by the tension of the spring above the valve. As the pressure in the secondary circuit lowers to the proper level, the valve spring pressure overcomes the resistance by the air below the valve and opens it again. This type of pressure-reducing valve is called a **constant reduced pressure valve**. Regardless of the amount of pressure in the main circuit, the pressure in the secondary circuit will remain the same.

A second type of pressure-reducing valve is the **fixed-amount reduction valve** (fig. 5). This valve operates by maintaining a balance between the pressure of the main circuit and the combined pressures of the valve spring and secondary circuit. Thus, the amount of reduction will always remain the same. However, the pressure in the secondary circuit will fluctuate as the pressure in the main circuit fluctuates. Yet the amount of reduction between the main circuit and the secondary circuit remains constant.

Pressure sequence valves are used to direct air from one branch of a circuit to another branch after the needs of the first branch are filled. They operate much like a relief valve. Figure 6 shows a sequence valve closed. At this point, the system is producing only enough air for the primary circuit. Figure 7 shows a sequence valve open and supplying air to both the primary and secondary circuits. When the pressure in the primary circuit reaches a preset point, pressure from the primary circuit forces the diaphragm downward. The downward movement of the diaphragm pushes the rod downward on the spool valve. As the spool valve moves downward, it lifts the ball check from its seat, allowing air to flow through the secondary circuit. The valve will remain in the open position as long as the system provides more air than that required by the primary circuit.

Directional Control Valves

Three types of control valves are used to direct air from one circuit or branch to

another. They are check valves, rotary valves, and spool valves.

Check valves are simple one-way valves. They are an application of the valve used as a relief valve. Air flowing in one direction opens the valve and permits the air to pass, while air flowing in the opposite direction closes the valve and prevents the air from passing.

Rotary valves (fig. 8) are cylinders that are machined to fit snugly in a housing. The housing has ports that are connected to the circuits that perform work and to the atmosphere. The cylinder has matching holes that align with those in the housing when turned to the "on" position. The holes in the cylinder do not align in any other position. The cylinder may be turned by a hand lever or pneumatically.

Spool valves are the ones most often used in pneumatic systems to control all phases of the system. Two features of the spool valve make it more desirable than other types of valves. These are its **adaptability** and **compactness**. A spool valve can be adapted to fit many different functions by adding lands and ports. (**Lands** are the raised sections on each side of a groove.) A spool valve can operate alone, or multiple spools can be stacked together to serve several functions.

Figure 9 shows a five-ported, four-way, two-position valve. It would control the air to a double-acting piston cylinder. Pilot air from a control directs air to the chamber on the left end of the valve. This moves the valve to the right. Notice that the spool valve is positioned at the end of the housing. In this position, compressed air flows from the compressor through the valve to one side of the double-acting piston. Also, air from the opposite side of the piston is exhausted through the valve and to the atmosphere.

Figure 10 shows the valve as it operates the double-acting piston in the opposite direction. The pilot air on the left side has been released and is directed to the chamber on the right side. This moves the spool valve to the left side of the housing. In this position, compressed air is now directed to the opposite side of the piston from that shown in figure 9. Also, the air that was compressed in figure 9 is now exhausted through the valve and into the atmosphere. This cycle is repeated each time the piston

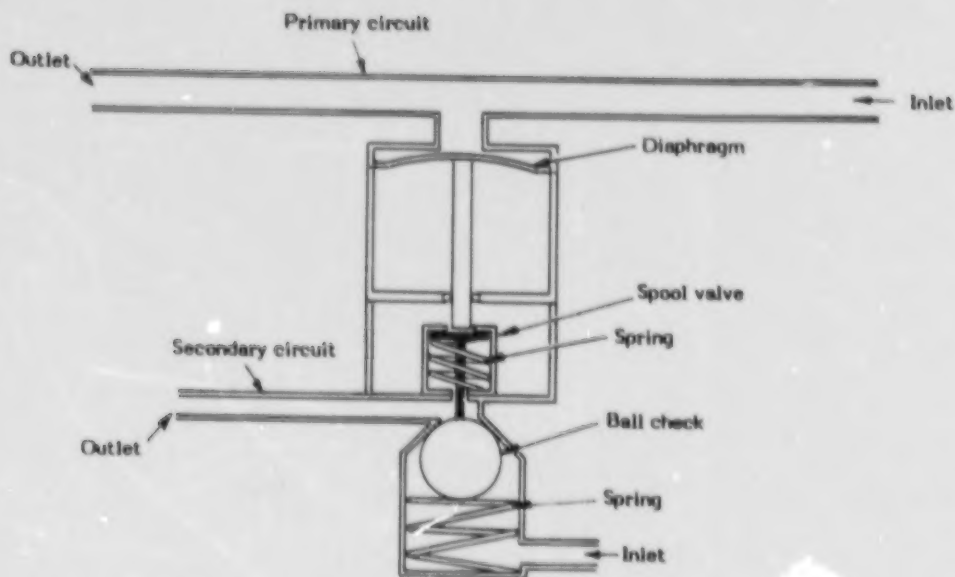


Fig. 6. Primary circuit has not overcome pressure on the diaphragm, and valve remains closed.

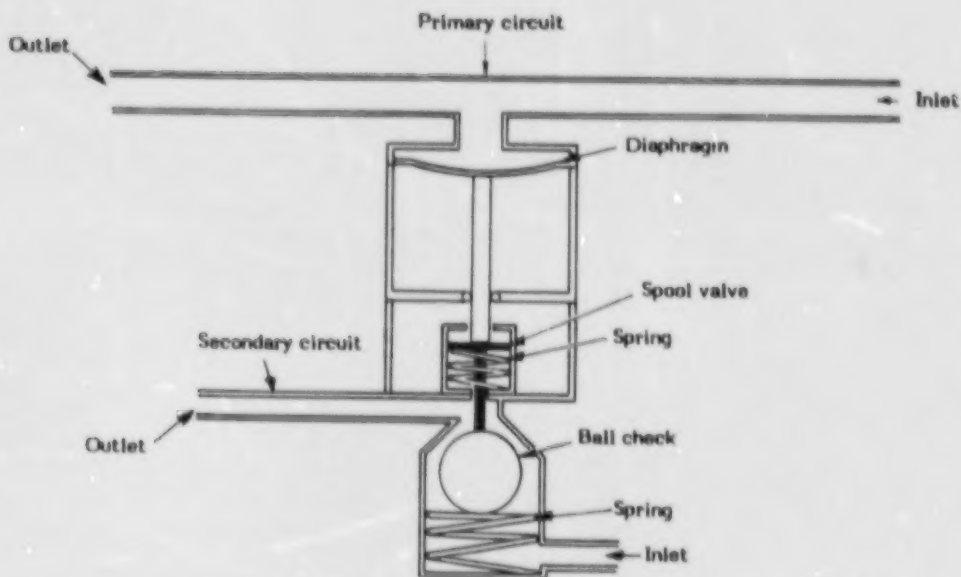


Fig. 7. Primary circuit has overcome diaphragm pressure, and valve is opened.

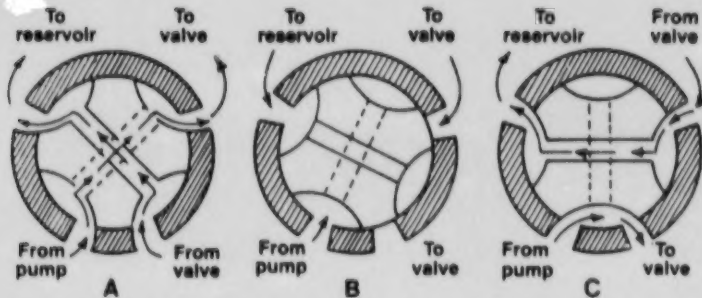


Fig. 8. Rotary valve positioned to do work (A), in the off position (B), and positioned for different systems to work (C)

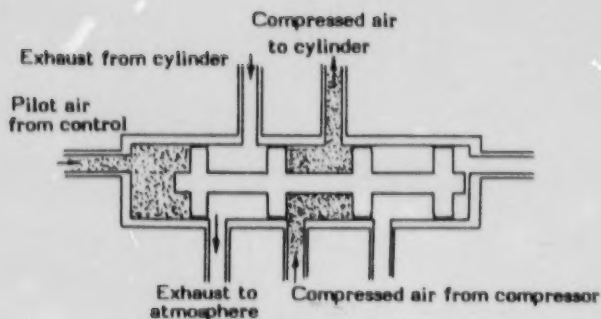


Fig. 9. Pilot air in left chamber moves spool valve to right.

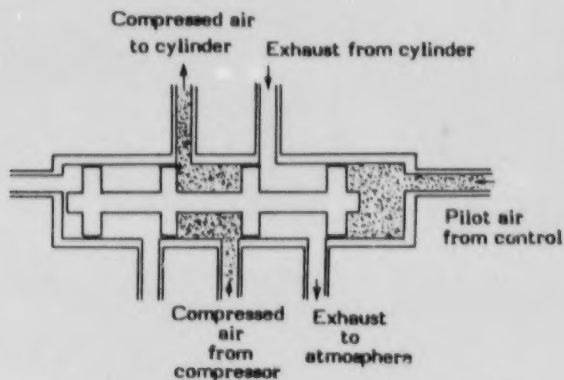


Fig. 10. Pilot air in right chamber moves spool valve to left, reversing operation.

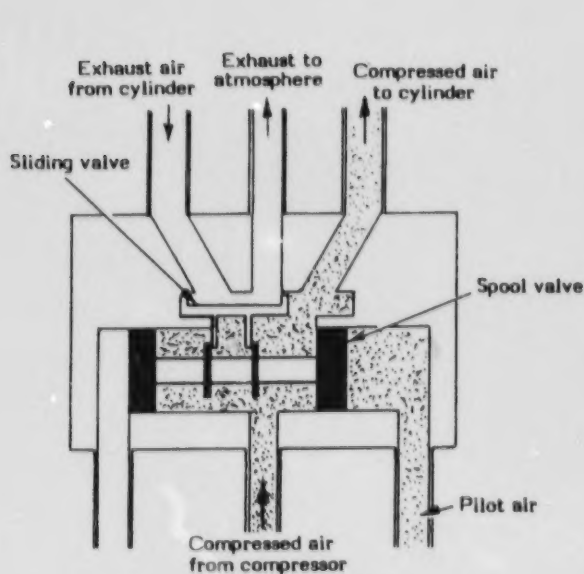


Fig. 11. Pilot air in right chamber moves spool valve and sliding valve to left.

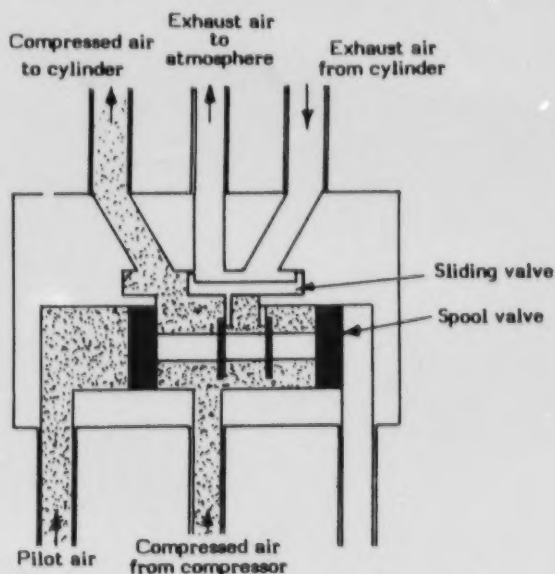


Fig. 12. Pilot air in left chamber moves spool valve and sliding valve to right, reversing operation.

moves from one end of the cylinder to the other.

Figures 11 and 12 show another type of spool valve that serves the same function as the one in figures 9 and 10. This type is easier to seal than the first type since the lands of the spool never have to move across the ports. Movement across the ports tends to wear the seals on the lands.

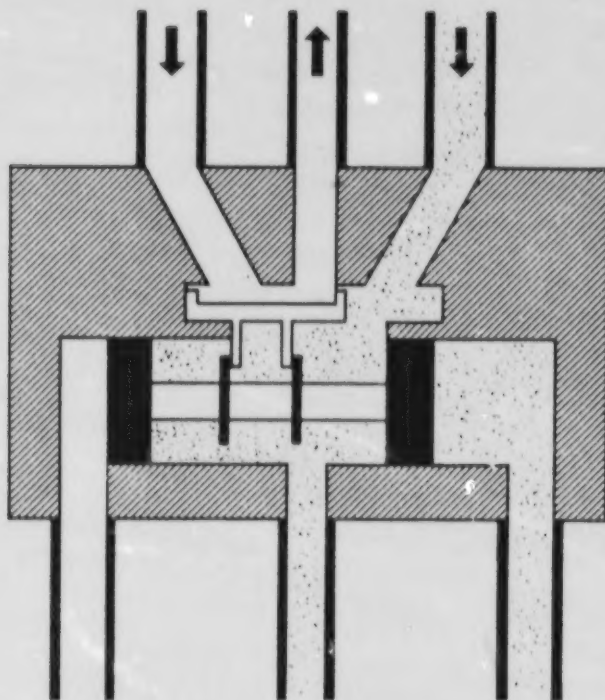
Figure 11 shows the valve as a control for a double-acting piston cylinder. Pilot air on the right side of the valve moves the spool valve to the left. This also moves the sliding valve to the left. Compressed air flows from the compressor through the valve to one side of the piston. Exhaust air from the opposite side of the piston flows through the sliding valve and is directed through the exhaust vent to the atmosphere.

Figure 12 illustrates the valve as it operates the piston in the opposite direction. Pilot air on the left side of the spool valve moves it to the right. This also moves the sliding valve to the right. Compressed air flows from the compressor through the valve and to the opposite side of the piston than it did in figure 11. Exhaust air from the opposite side of the piston is now directed through the sliding valve and out the exhaust vent to the atmosphere.

Exercise

1. Which functions of the pneumatic system do valves control?
2. What are the three functions of pressure control valves?
3. What is the sole function of a relief valve?
4. What are the working parts of a simple relief valve?
5. What must happen before a relief valve can open?
6. Under what condition is a pilot-operated relief valve used?
7. Which pneumatic pressure does the pilot valve control?
8. Under what condition must a pressure-reducing valve be used?
9. What are the two types of pressure-reducing valves?
10. What is the function of a pressure sequence valve?
11. Why is the sequence valve in figure 6 closed?
12. Trace the force that moves the ball check from its seat in figure 7.
13. What kind of a valve is a check valve?
14. How does the rotary valve work?
15. What features of the spool valve make it desirable?
16. How is the spool valve adapted for special functions?
17. How do the two working chambers of the valve shown in figures 9 and 10 relate to each other when the valve is moved from one end to the other?
18. Why is the type of spool valve shown in figures 11 and 12 easier to seal than that shown in figures 9 and 10?
19. In which direction does the spool valve move when pilot air is provided on the left side?
20. Where is the air exhausted when it leaves the valve?

PNEUMATICS



INSTRUCTOR'S GUIDE

Pneumatics

Instructor's Guide

Prepared by

Troy Notgrass

Published by

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COMPLIANCE STATEMENT

TITLE VI, CIVIL RIGHTS ACT OF 1964; THE MODIFIED COURT ORDER, CIVIL ACTION 5281, FEDERAL DISTRICT COURT, EASTERN DISTRICT OF TEXAS, TYLER DIVISION

Reviews of local education agencies pertaining to compliance with Title VI Civil Rights Act of 1964 and with specific requirements of the Modified Court Order, Civil Action No. 5281, Federal District Court, Eastern District of Texas, Tyler Division are conducted periodically by staff representatives of the Texas Education Agency. These reviews cover at least the following policies and practices:

- (1) acceptance policies on student transfers from other school districts;
- (2) operation of school bus routes or runs on a non-segregated basis;
- (3) nondiscrimination in extracurricular activities and the use of school facilities;
- (4) nondiscriminatory practices in the hiring, assigning, promoting, paying, demoting, reassigning, or dismissing of faculty and staff members who work with children;
- (5) enrollment and assignment of students without discrimination on the basis of race, color, or national origin;
- (6) nondiscriminatory practices relating to the use of a student's first language; and
- (7) evidence of published procedures for hearing complaints and grievances.

In addition to conducting reviews, the Texas Education Agency staff representatives check complaints of discrimination made by a citizen or citizens residing in a school district where it is alleged discriminatory practices have occurred or are occurring.

Where a violation of Title VI of the Civil Rights Act is found, the findings are reported to the Office for Civil Rights, Department of Health, Education and Welfare.

If there is a direct violation of the Court Order in Civil Action No. 5281 that cannot be cleared through negotiation, the sanctions required by the Court Order are applied.

TITLE VII, CIVIL RIGHTS ACT OF 1964; EXECUTIVE ORDERS 11246 and 11375; TITLE IX 1973 EDUCATION AMENDMENTS; REHABILITATION ACT OF 1973 AS AMENDED; 1974 AMENDMENTS TO THE WAGE-HOUR LAW EXPANDING THE AGE DISCRIMINATION IN EMPLOYMENT ACT OF 1967; VIETNAM ERA VETERANS READJUSTMENT ASSISTANCE ACT OF 1972 AS AMENDED IN 1974.

It is the policy of the Texas Education Agency to comply fully with the nondiscrimination provisions of all federal and state laws and regulation by assuring that no person shall be excluded from consideration for recruitment, selection, appointment, training, promotion, retention, or any other personnel action, or be denied any benefits or participation in any programs of activities which it operates on the grounds of race, religion, color, national origin, sex, handicap, age, or veteran status (except where age, sex, or handicap constitute a bona fide occupational qualification necessary to proper and efficient administration). The Texas Education Agency makes positive efforts to employ and advance in employment all protected groups.

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Foreword

This publication is one of a series of self-contained instructional materials for trade and industrial students. Each student who uses this material can work at his or her own pace, learning those things that best fit her or his specific needs. The design of the material makes it possible to relate work experience on the job to information studied at school.

Although the material is individualized, it should be used under the supervision of an instructor. For that reason, two basic publications are offered, a student's manual and an instructor's guide.

The **student's manual** is for the use of the person in training. Each assignment includes appropriate information, objectives to be met, and exercise questions that help the student meet those objectives.

The **instructor's guide** provides information to the instructor on how to use the material to the best advantage of the student, answers to exercise questions and assignment test questions, one set of assignment tests, and a work sheet.

Every effort has been made to produce a publication that addresses the unique needs of our current student population. Students with limited English proficiency (LEP), as well as handicapped, educationally disadvantaged, and nontraditional students may require modification of the material in this publication. The professional staff of EIMC will gladly work with any instructor having these students to show how the instructional material can be adapted for specific individualized instruction. Consult local, state, and federal agencies that offer assistance and guidance and that can provide sound recommendations for productive classroom management.

Kathryn R. Allen, Ph.D.
Director, Extension Instruction
and Materials Center

Notes for the Instructor

The student's self-contained manual is designed for use in presenting related technical information to (1) groups of trade and industrial students with a variety of vocational objectives and (2) homogeneous groups in which the learning levels of individual students vary considerably. The manual is not intended to be used as a type of correspondence course, but must be used by students under the direct supervision of an instructor.

This particular manual, being one on basic information and techniques, should be used as an introduction to the field of pneumatics.

This instructor's guide is designed to help you make certain that each student gets the most benefit possible out of both the student's manual and what is learned at the training station. It provides the answers to exercises and assignment test questions. It also provides a work sheet to help in coordinating work experiences with the assignments.

The instructor should keep all answers to questions. The actual assignment tests and work sheet can be removed from this book to make them easier to use or reproduce. For greater convenience, this manual is punched for notebook use.

Academic Background Required

The student must have the correct background in order to succeed in this field.

English. The student should make good grades in English and be able to read at the tenth-grade level. After entering the trade, the student must be able to read at the twelfth-grade level in order to understand the specifications in various service manuals.

Mathematics. The student should be able to work with fractions, decimals, and percentages. An understanding of the metric system will help with sizes of metric wrenches and metric specifications.

Science. An introductory course in physical science will help the student understand factors such as momentum, mechanical advantage, the venturi principle and others related to pneumatics.

Aptitudes. The student should have a high mechanical aptitude and a high degree of manual dexterity.

The above information may be used in counseling students who express a desire to train in this field. It also could be useful to school counselors, teachers, and others who may have an opportunity to counsel potential vocational students.

Organization

The student's manual is designed to use as many fundamental teaching principles as possible. Each assignment has four parts, and each part is based on one of these principles.

Objectives. The first fundamental teaching principle is that the student should be **informed** at the outset what he or she should learn from the assignment. This is done through a statement of objectives at the beginning of each assignment. These are performance objectives that can be tested on completion of the assignment.

Technical Information. The second teaching principle is that technical information should be presented in **complete, but concise form**. The information is presented step-by-step, going from the simple to the complex, thus making learning easier. Of the

four teaching principles discussed here, this is by far the most important. The biggest favor you can do for your students is to persuade them that, if they learn the information presented, the grades will take care of themselves.

Exercise. The third teaching principle is that technical information is better learned if it can be **applied** as soon as possible after presentation. This is done through exercise questions for each assignment. The questions are phrased to provoke thought about, and evaluation of, the technical information. You should emphasize to the students that both the objectives and the technical information should be read before they attempt to answer the exercise questions. Answers may be useful when helping a student who is having difficulty with an assignment exercise. The students' answers do not have to be stated in exactly the same words presented in the text.

Tests. A fourth teaching principle is that the effectiveness of the assignment should be **evaluated**. This is made possible by brief assignment tests provided in this guide. Each test is based on the objectives stated for the assignment. A test should be given on completion of the assignment. Answers to assignment tests provide a quick reference for grading. **You should retain all answers, for obvious reasons.**

Tests and Work Sheet

The last section of this guide has been placed after a divider page so that the tests and work sheet can be removed for use with individual students or for reproduction. You may reproduce the tests and work sheet **without permission**, or you can order separate sets of just this material from this Center.

The work sheet is provided for your convenience in (1) planning how job experience is to be matched to related instruction in the student's manual and (2) keeping daily records as the student progresses through the year. The work sheet is designed so that you may follow any sequence of instruction desired. The assignments are coded and can be easily listed opposite the related jobs. Also, space is provided for other records you may wish to include on the work sheet.

**Answers
to
Exercises**

Exercise 1

How to Use This Manual

1. Both want the learning process to be as easy as possible.
2. (1) the learning objectives
(2) the technical information
(3) the exercise
(4) the assignment test
3. They tell you what you should be able to remember after completing the assignment.
4. to give a clue as to the subject matter of the assignment test
5. First read the objectives, then read the technical information, and then answer the questions in the exercise.
6. to guide you over the same information three times
7. How you keep your notebook is important since your notebook should show anyone what you have studied in the program.
8. how much you have learned
9. because you will have covered the information three times before taking the test
10. If you fail to learn, the author, through this manual, has failed to teach.

Exercise 2

Introduction

1. the Greek word for air
2. (1) Air is available at any place in unlimited quantities.
(2) Air can be easily transported through pipelines to any point desired.
(3) Air is stable even under temperature changes.
(4) Compressed air is clean.
(5) Pneumatic speeds and forces are infinitely variable.
(6) Pneumatic tools and equipment are overload safe.
3. (1) Compressed air requires proper preparation.
(2) It is not possible to achieve uniform and constant equipment speeds with compressed air.
(3) In most instances, compressed air is not an inexpensive means of conveying power.
4. Since they do conform to any shape, they are easily piped almost anywhere.
5. It is impossible to maintain a constant, or even, pressure during use.
6. Every square inch of the inside of a container, regardless of its shape, has an equal pressure exerted on it.
7. Pressure is defined as force divided by the area over which the pressure is distributed.
8. Force equals pressure times area.
9. by increasing the area on which the pressure is applied
10. the difference in the areas of the pistons
11. to increase (multiply) force

Exercise 3

Air Compressors

1. that a measurable volume of air is displaced in a complete cycle of a reciprocating piston or revolving rotor equipped with lobes or vanes
2. atmospheric pressure
3. low and medium pressure requirements
4. to increase the air pressure
5. The air charge has been compressed to a smaller volume.
6. It would compress the air charge to the same pressure that was provided by the first stage.
7. The two strokes overlap.
8. to prevent contamination of the air by the lubricating oil for the crankshaft and piston
9. two or three
10. As the impellers rotate, air is trapped in the opening between the lobes and housing. The air is forced into the outlet opening when the lobes mesh.
11. to reduce the impulse of air and give a smooth airflow
12. It is not as noisy as the two-lobed impeller and it delivers a smoother flow of air.
13. It delivers the greatest amount of air from a given sized housing and uses less power than the three-lobed impeller.
14. by the sliding vanes around the rotor forming a seal with the housing
15. the chamber being enlarged as the vanes move outward
16. the chamber becoming smaller as the vanes move in
17. It is compact, quiet running, and delivers a smooth, steady flow of air.
18. at 15,000 to 30,000 rpm
19. near the center of the impeller
20. the shape of the housing
21. to increase the air pressure and route it to the next stage

Exercise 4

Plastic Piping

1. This permits the air to flow in two directions to the point of greatest use.
2. the resistance in the piping system to airflow
3. 10 percent
4. Pipe cannot be serviced inside a wall.
5. to prevent condensation from filling the pipe
6. because it is noncorrosive and is inexpensive to install
7. by solvent welding
8. It remains serviceable up to 230°F, and the pipe itself is self-extinguishing.
9. installing pipe that did not meet specifications or using incorrect procedures in making joints
10. Solvent welding compounds are flammable and evaporate quickly.
11. a fine-toothed hand saw and a miter box or a rotary cutter
12. Failure to remove the ridges will result in the solvent being scraped from the socket surface.

13. about halfway into the socket
14. the bell-mouthed shape of the socket
15. a full, even coating that does not leave a puddle in the bottom of the fitting
16. to ensure an even distribution and absorption of the solvent
17. The interference fit will force the pipe out if the joint is released too soon.
18. A ring or bead should go all the way around the joint if enough solvent was used.
19. to help the joint cure faster

Exercise 5

Copper Piping

-
1. compression joints and flared joints
 2. a tubing cutter
 3. Remove ridges from the inside, and burrs from the outside.
 4. up against the seat of the fitting
 5. Compressing it too much will cause a restriction in the fitting.
 6. 1/16 inch
 7. with steady, even turns
 8. To do so will cause it to fail.
 9. to prevent twisting the tubing
 10. 500°F
 11. It is lower.
 12. capillary action
 13. a half-round file
 14. The surfaces must be absolutely clean for the filler metal to wet the surfaces easily and evenly.
 15. If too much metal is removed, the capillary action will be adversely affected.
 16. about 1/4 to 1/2 inch more than the depth of the socket.
 17. It should not be used.
 18. (1) It protects the base metal from oxidation during the heating process.
(2) It breaks up oxides that form on the surface and floats them to the top and out of the joint.
 19. Apply the flux with a brush in a thin, even layer, using only enough flux to properly cover the surfaces to be joined.
 20. The flux is either wet or greasy, and it will pick up dust and dirt if tubing and fittings are allowed to lie around.
 21. Misalignment will cause the tubing to be cocked in the fitting. This will affect the soldered joint by changing the space between the tubing and the fitting.
 22. Heating is the only step that requires a sense of feel and skill in performing.
 23. (1) Make sure the joint is properly prepared for soldering.
(2) Do not overheat.
 24. so the solder can be drawn into it evenly
 25. (1) controlling the size of the flame used
(2) controlling the length of time the flame is applied to the joint
 26. First, heat the tubing before heating the fixture. Apply the heat just beyond the end of the fitting for a short time. Then move the flame back and forth to heat the fitting and the tubing alternately. The flame should point from the fitting to the tubing.
 27. so that the sharp point of the inner cone just touches the metal
 28. by contact with the joint

29. when the solder begins to melt
30. after the socket has filled

Exercise 6

Conditioning Compressed Air Systems

1. It is introduced into the system along with the air.
2. More moisture is present in a given volume of space than that volume of air can contain, so it condenses out.
3. to cool the air and cause the moisture to condense
4. a chemical process
5. because it loses its effectiveness in time
6. to filter out the oil before it gets to the drier
7. a physical process
8. by collecting or adsorbing the water on the surfaces of the drying agent
9. granular form
10. by pumping hot, dry air through it
11. by cooling the air to its dew point
12. dirt, rust particles, etc.
13. It throws the heavier particles and droplets of water outward.
14. to deflect the incoming air upward and out without disturbing the dirt and droplets of water underneath it
15. 0.01 micron
16. to keep the operating pressure constant even though the compressor pressure and the air consumption rate may fluctuate
17. the operating pressure on one side and the spring pressure against the outlet pressure side
18. (1) to reduce friction and wear
(2) to protect the system from corrosion
19. the venturi principle
20. a low-pressure area or partial vacuum
21. Air pressure on the lubricating fluid surface in front of the venturi is greater than that on the oil passage at the venturi. This forces the oil up through the oil passage.

Exercise 7

Pressure Gauges and Volume Meters

1. As pressure builds up inside, it attempts to straighten out.
2. Tip travel is directly proportional to the amount of pressure inside the element.
3. It is easier to manufacture in uniform quality and large quantity. It also occupies less space.
4. They provide much greater movement or tip travel
5. by using levers or gears
6. There is less lost motion and friction to interfere with accurate gauging of pressures.
7. The first tube is mounted in an upright position, and the second tube is mounted 180° from the first tube. The pressures cause the two tubes to pull against each other.

8. the energy from the flowing air
9. (1) a ball-like center section
(2) a pin
(3) a disk
10. over and under the piston or disk

Exercise 8

Pneumatic Working Elements

1. It imparts a straight back-and-forth movement.
2. one
3. a return spring or gravity
4. to prevent a buildup of air pressure or the creation of a vacuum
5. the rod and its seal
6. those where only small piston movement is required
7. It permits a larger stroke than that of a regular single-acting cylinder. It also reduces friction between the piston and the cylinder.
8. to supply pneumatic pressure to the cylinder and to discharge pressure from the cylinder
9. the atmosphere
10. to protect them from the impact of sudden stops
11. a valve
12. It has a rod extending from each end of the cylinder.
13. It has bearings at each end of the cylinder.
14. motion that rotates from side to side
15. the rotating shaft
16. the inside cylinder surfaces
17. two
18. a housing and two gears of equal size
19. between the teeth and the motor housing and between the teeth where the two gears mesh
20. the difference between the pneumatic pressure on the inlet side and the atmospheric pressure on the discharge side
21. a circular housing, a rotating cylinder, and sliding vanes
22. It is offset in the housing.
23. centrifugal force
24. There is more volume on the side with the extended vanes and there is more pressure also.
25. Air is forced through the discharge port.

Exercise 9

Pneumatic Valves

1. (1) They control the pressure throughout the system.
(2) They direct the air to the proper circuits.
(3) They regulate the volume of air to each circuit.
2. (1) to limit the pressure in a pneumatic system
(2) to unload the excess pressure from the pump when proper pressure for the system has been exceeded
(3) to regulate the pressure at which air enters a circuit
3. to prevent the pneumatic system from developing pressure above a given amount
4. a valve, a seat, and a spring with calibrated tension
5. The pressure must become greater than the safe operating range, allowing pneumatic pressure to overcome the spring tension.
6. when the valve must handle large volumes and when there must be little difference between when the valve opens and when it closes
7. the pneumatic pressure on the backside of a relief valve
8. when the main circuit delivers high or fluctuating pressures even though a branch of the circuit requires a lower constant pressure
9. (1) the constant reduced pressure valve
(2) the fixed-amount reduction valve
10. to direct air from one branch of a circuit to another branch after the needs of the first branch are filled
11. The system is producing only enough air for the primary circuit.
12. from the diaphragm to the rod to the valve spool to the ball check
13. a simple one-way valve
14. The cylinder has matching holes that align with those in the housing when turned to the "on" position.
15. its adaptability and compactness
16. by adding lands and ports
17. The side of the valve that serves as the exhaust becomes the compression side when the valve is moved, and the side that serves as the compression side becomes the exhaust side.
18. because the lands never move across the ports
19. to the right
20. to the atmosphere

**Answers
to
Assignment Tests**

Test 1**How to Use This Manual**

1. exercise
2. objectives
3. technical information
4. assignment test

Test 2**Introduction**

1. unlimited
2. uniform / constant
3. force / area
4. pressure / area

Test 3**Air Compressors**

1. Atmospheric pressure
2. compressed / smaller
3. two / three
4. housing
5. housing
6. stage

Test 4**Plastic Piping**

1. loop
2. 10
3. noncorrosive
4. rotary
5. solvent

Test 5**Copper Piping**

1. three
2. cleaning
3. Flux
4. fitting / tubing
5. joint

Test 6**Conditioning Compressed Air Systems**

1. air
2. adsorption
3. dew point
4. moisture
5. venturi

Test 7**Pressure Gauges and Volume Meters**

1. straighten out
2. Tip travel
3. levers
4. flowing air
5. disk

Test 8**Pneumatic Working Elements**

1. return spring
2. diaphragm
3. cushions
4. housing
5. vane

Test 9**Pneumatic Valves**

1. pressure / air
2. pressure-reducing
3. holes / housing
4. compactness

**Assignment Tests
and
Work Sheet**

**for
Pneumatics**

For Your Convenience . . .

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- Instructors who do not want to reproduce the material can purchase separate sets of just this section from Extension Instruction and Materials Center, The University of Texas at Austin, P.O. Box 7218, Austin, TX 78713-7218.
- Each assignment test is based on a specific assignment.
- The work sheet is provided for use as a weekly log if the instructor desires. On the sheet is a listing of the contents of the student's manual for coordinating assignments with work experience.

Test 1

How to Use This Manual

1. The four parts of each assignment are the objectives, the technical information, the _____, and the assignment test.
2. The _____ tell you what to look for in the technical information.
3. The exercise is used to guide you over the _____ a third time.
4. The _____ is designed to show how well you have mastered the technical information.

Test 2
Introduction

1. Air is available at any place in _____ quantities.
2. It is not possible to achieve _____ and _____ equipment speeds with compressed air.
3. The formula for finding pressure is that pressure equals _____ divided by the _____.
4. The formula for finding the force is that force equals _____ times _____.

Test 3

Air Compressors

1. _____ pushes air into the air chambers of the compressors.
2. The second stage of a two-stage air compressor is smaller than the first stage because the air charge is _____ and occupies a _____ volume.
3. The two rotors (impellers) of a lobe-type compressor may have _____ or _____ lobes.
4. The air chamber of a sliding vane compressor is formed by the sliding vanes, the rotor, and the _____.
5. The shape of the _____ of a turbine compressor transforms the high velocity of the air into pressure.
6. Each _____ of a radial flow air compressor increases the air pressure.

Test 4
Plastic Piping

1. A pneumatic system designed as a _____ permits air to flow in two directions to the point of greatest use.
2. The pressure drop should not exceed _____ percent.
3. Both PVC and CPVC form _____ joints when welded, even in locations where moisture is always present in the system.
4. Rigid plastic pipe should be cut with a fine-toothed saw or a _____ cutter.
5. The fitting should be twisted one-quarter of a turn after the pipe is inserted to ensure an even distribution and absorption of the _____.

Test 5
Copper Piping

1. A hacksaw blade should have at least _____ teeth in contact with the tubing at all times.
2. It is important to prevent removing any more material from the tubing than possible during the _____ step.
3. _____ dissolves oxides and floats them out of the joint.
4. The flame should be pointed from the _____ to the _____ during soldering.
5. The solder should be melted by contact with the _____.

Test 6

Conditioning Compressed Air Systems

1. Moisture is introduced into the pneumatic system along with the _____.
2. The _____ drier collects moisture on the surfaces of the drying agent.
3. The low-temperature drier removes air by dropping the temperature of the air to its _____.
4. Filters remove _____ and noncompressible particles.
5. Most lubricators for pneumatic systems operate on the _____ principle.

Test 7

Pressure Gauges and Volume Meters

1. As pressure builds up inside a Bourdon tube, it attempts to _____
_____.
2. _____ is directly proportional to the amount of pressure inside the Bourdon tube.
3. The motion of C-tubes can be increased by the use of _____ or gears.
4. The energy from the _____ powers a nutating piston meter.
5. The three major parts of a nutating piston meter are (1) a ball-like center section, (2) a pin, and (3) a _____ or piston.

Test 8

Pneumatic Working Elements

1. A _____ or gravity returns the piston of a single-acting piston to its original position.
2. A _____ cylinder would be used in a situation in which only small movement is required.
3. Pneumatic _____ are used to protect cylinders from impact from sudden stops.
4. A gear motor consists of a _____ and two gears.
5. A _____ motor has an offset for the cylinder in order to provide for an air chamber.

Test 9

Pneumatic Valves

1. Pressure control valves (1) limit the pressure in the system, (2) unload excess pressure, and (3) regulate the _____ at which _____ enters a circuit.
2. A _____ valve is used when the main circuit delivers high or fluctuating pressures.
3. When a rotary valve is turned on, the _____ in the cylinder align with those in the _____.
4. Spool valves are desirable because of their adaptability and _____.

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FOR COORDINATING JOBS WITH
RELATED INSTRUCTION USING
PNEUMATICS

This form is for your convenience in planning and keeping records of training. Contents of the student's manual are at the left. The columns below provide space for listing job experiences for the individual student and assignment numbers and other references related to each job. Blanks are large and divided by days so the teacher and student can list other information that might be useful in a weekly log.

Student _____

Training Station _____

JOB EXPERIENCES	RELATED INSTRUCTION
Monday Work Hrs:	
Tuesday Work Hrs:	
Wednesday Work Hrs:	
Thursday Work Hrs:	
Friday Work Hrs:	